SCIENCE LIBRARY

THIS NUMBER COMPLETES VOLUME 40

Volume 40 December, 1935 Number 6

SOIL SCIENCE

Editor-in-Chief
JACOB G. LIPMAN

Associate Editor
HERMINIE BROEDEL KITCHEN

Contents

The Relation of Soil Treatment to the Nodulation of Peanuts. H. B. MANN . 423

The Relation of Soil Erosion to Certain Inherent Soil Properties . J. F. LUTZ . 439

The Influence of Exchangeable Sodium in the Soil on Its Properties as a Medium for Plant Growth. E. I. RATNER 459

A Sedimentation Tube for Analyzing Water-stable Soil Aggregates. RALPH C. COLE AND N. E. EDLEFSEN 473

A Method for Making Mechanical Analysis of the Ultimate Natural Structure of Soils. GEORGE JOHN BOUYOUCOS 481

The Rôle of Plant Constituents in the Preservation of Nitrogen in the Soil. SELMAN A. WAKSMAN AND I. J. HUTCHINGS 487

INDEX 499

Published Monthly by THE WILLIAMS & WILKINS COMPANY
MT. ROYAL AND GUILFORD AVENUES, BALTIMORE, MARYLAND, U. S. A.

Made in United States of America

SOIL SCIENCE

FOUNDED BY
RUTGERS COLLEGE
NEW BRUNSWICK, N. J.

ADVISORY STAFF

A. W. Blair, J. S. Joffe, L. L. Lee, H. C. McLean, G. T. Nightingale, A. L. Prince, J. W. Shive, H. B. Sprague, R. L. Starkey, and S. A. Waksman, New Jersey Agricultural Experiment Station, New Brunswick, N. J.

CONSULTING EDITORS

F. J. ALWAY
University of Minnesota, St. Paul, Minn.

K. ASO
Imperial University, Tokyo, Japan

C. BARTHEL
Lantbrukshögskolan, Uppsala, Sweden

RICHARD BRADFIELD
College of Agriculture, Ohio State University, Columbus, Ohio

P. E. BROWN
Iowa State College of Agriculture, Ames, Iowa

B. C. BURT
Imperial Council of Agricultural Research, New Delhi, India

H. J. CONN
New York State Experiment Station, Geneva, N. Y.

ALBERT DEMOLON
Ministry of Agriculture, Paris, France

E. B. FRED
University of Wisconsin, Madison, Wis.

V. V. GEMMERLING
Agronomitcheskii Institute, Moskovskii Universitat, Moscow, U. S. S. R.

J. E. GREAVES
Utah Agricultural College, Logan, Utah

ACH. GREGOIRE
Agricultural Experiment Station, Gembloux, Belgium

B. L. HARTWELL
143 Armington St., Edgewood, R. I.

D. J. HISSINK
Soil Science Institute, Groningen, Holland

O. LEMMERMANN
Institut für Agrikulturchemie u. Bakteriologie der Landwirtschaftlichen Hochschule, Berlin-Dahlem, Germany

C. B. LIPMAN
University of California, Berkeley, Calif.

BURTON E. LIVINGSTON
Johns Hopkins University, Baltimore, Md.

HENRIK LUNDEGÅRDH
Centralanstalten för jordbruksförsök Stockholm Sweden

T. L. LYON
Cornell University, Ithaca, N. Y.

M. M. McCOOL
Boyce-Thompson Institute, Yonkers, N. Y.

W. H. MACINTIRE
University of Tennessee, Knoxville, Tenn.

S. MATTSON
Lantbrukshögskolan, Uppsala, Sweden

E. A. MITSCHERLICH
University of Königsberg, Prussia

C. A. MOOERS
University of Tennessee, Knoxville, Tenn.

D. N. PRIANISHNIKOV
Timiryazev Academy, Moscow, U. S. S. R.

THEO. REMY
Institut für Boden- und Pflanzenbaulehre, Bonn a. Rh., Prussia

G. ROSSI
Royal Agricultural High School in Portici, Naples, Italy

E. J. RUSSELL
Rothamsted Experimental Station, Harpenden, England

O. SCHREINER
U. S. Department of Agriculture, Washington, D. C.

ALEXIUS A. J. DE'SIGMOND
Royal Hungarian Joseph University of Technical Sciences, Budapest, Hungary

J. STOKLASA
Technical High School, Prague, Czechoslovakia

CHAS. E. THORNE
Ohio Experiment Station, Wooster, Ohio

N. M. TULAIKOV
Agricultural Experiment Station, Saratov, U. S. S. R.

G. WIEGNER
Landwirtschaftliche Hochschule, Zürich, Switzerland

S. WINOGRADSKY
Pasteur Institute, Paris, France

Entered as second-class matter, May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879.

Copyright, 1935, The Williams & Wilkins Company

THE RELATION OF SOIL TREATMENT TO THE NODULATION OF PEANUTS[1]

H. B. MANN[2]

North Carolina Agricultural Experiment Station

Received for publication March 15, 1935

The use of calcium carbonate and calcium sulfate in the production of large type peanuts has become an almost universal practice. Little attention has been given, however, to the effects of these salts except that upon the final yield of nuts. Under some conditions on application of either or both of these materials may mean the difference between crop failure and success, whereas under other conditions they are of no apparent value. What these conditions are has not been determined. A part of the investigations designed to study this problem has shown certain relationship between nodulation and soil treatments.

HISTORICAL REVIEW

Previous work along this line with peanuts has been limited. Duggar (5) working with Spanish peanuts reported decreased nodulation during the first 6 weeks resulting from separate applications of superphosphate, basic phosphate, and hydrated lime in immediate contact with the seed. Increased nodulation was noted from applications of 200 pounds per acre of sulfur. Neither the type of soil used in these investigations nor its reaction was reported.

Although a vast amount of work has been done with legumes in general, there is no agreement among investigators as to the effect of various inorganic salts on nodulation. It would appear from the work of Pitz (13), Reimer and Tartar (15), and Neller (9) that calcium sulfate and sulfur exert a stimulating effect on the nodulation of legumes. Wilson (17), however, found that not only calcium sulfate but sulfates in general had a depressing effect upon the nodulation of soybeans. Carbonates appeared to have a stimulating effect, most of which he attributed to the influence of the alkaline radical with which the carbonates were combined.

Supported by many early investigations, and the comparatively recent ones of Prucha (14), Fellers, (6) Wilson (17), Albrecht and Davis (2, 3), and Scanlan (16), calcium carbonate is usually considered as having a stimulating effect upon nodulation. However, Perkins (10, 11) was unable to get increased nodulation

[1] Published with the approval of the director of the North Carolina Experiment Station as paper 82 of the Journal Series.

[2] Agronomist in soil fertility of the North Carolina Agricultural Experiment Station.

of soybeans from the use of either calcium or potassium compounds. Harmful effects from large applications of calcium oxide or calcium carbonate have been reported by several German investigators, the more recent of whom are Pfeiffer and Simmermacher (12), Merkenschlager (8), and Boas and Merkenschlager (4).

These conflicting results serve to illustrate the necessity of further investigations along these lines as well as to indicate the importance of such factors as growth period, soil type, previous soil treatment, and amount of chemicals applied. This investigation was undertaken to give further information regarding the effect of the latter factors upon nodulation of peanuts.

EXPERIMENTAL METHODS

Glazed pots of 2½ gallon capacity, filled with a definite amount of soil for each type used, were uniformly inoculated with a commercial peanut culture and maintained as nearly as possible at a constant optimum moisture content. Seven Virginia Bunch peanut seeds were planted in each pot and after germination were thinned to five plants. Those were grown in the greenhouse, and at various stages of growth the soil was washed from the roots of the plants and nodulation records were made. Soil samples were taken for pH determinations, which were made by the quinhydrone method, and dry weights of plants recorded. All results reported are the average of duplicate treatments.

NODULATION AND GROWTH OF PEANUTS AND THE pH OF SOILS AS INFLUENCED BY CALCIUM CARBONATE, CALCIUM SULFATE, AND SULFUR

There are two general types of soil on which large peanuts are usually grown. Norfolk sandy loam, which is light in color, well drained, sandy, and low in organic matter, represents one of these. The other type as represented by the Coxville fine sandy loam is dark in color, less well drained, finer in texture, and higher in organic matter. Experiments were made with these two types of soil to determine the effects of applications of calcium carbonate, calcium sulfate, and sulfur upon nodulation and growth of peanuts and the reaction of the soil.

Virgin Norfolk sandy loam soil

On February 24, 1932, 48 pots were set up with virgin Norfolk sandy loam soil (pH 5.3) as outlined under experimental methods. These were divided into eight series of six treatments each, the latter as follows: (*a*) 2,000 pounds of calcium carbonate per acre; (*b*) 2,000 pounds calcium sulfate; (*c*) 400 pounds of ground sulfur; (*d*) 400 pounds of ground sulfur and 2,000 pounds of calcium carbonate; (*e*) 2,000 pounds of calcium sulfate and 2,000 pounds of calcium carbonate; (*f*) left untreated for check. The materials were thoroughly mixed with the entire amount of soil in each pot.

The number of nodules per pot of five plants, the dry weights of plants, and the pH of soils were determined on duplicate series on March 14, March 30, April 11, and August 24, 1932. When the last records were made on August 24

the peanuts had reached the stage of maturity at which commercial nuts are dug. Treatments and results are shown in table 1.

Eighteen days after planting, when the first series of plants were harvested, no nodules had developed sufficiently on any of the roots to be identified. At all other stages of growth as compared with the checks calcium carbonate increased nodulation. This increase became greater as the plants developed. Calcium sulfate both retarded and reduced nodulation. No nodules were found in the calcium sulfate pots until the third series was harvested 48 days after planting. Four hundred pounds of sulfur per acre prevented nodulation at all stages of growth, whereas the combination of sulfur and calcium carbonate produced about the same number of nodules as the checks. The combined application of calcium sulfate and calcium carbonate had very little

TABLE 1

Nodulation and growth of peanuts and the pH of virgin Norfolk sandy loam soil as influenced by calcium carbonate, calcium sulfate, and sulfur

Original pH 5.3. Planted February 24, 1932

TREATMENT PER ACRE	AVERAGE NUMBER OF NODULES PER POT (5 PLANTS)				AVERAGE DRY WEIGHT OF PLANTS PER POT (5 PLANTS)				pH OF SOIL			
	Days after planting											
	18	34	48	180	18	34	48	180	18	34	48	180
					gm.	*gm.*	*gm.*	*gm.*				
None	0	12	160	405	3.5	5.8	10.2	27.4	5.25	5.40	5.40	5.10
2,000 lbs. $CaCO_3$	0	13	215	1,090	2.3	4.6	10.9	36.5	6.50	6.75	6.70	5.60
2,000 lbs. $CaSO_4$	0	0	50	175	2.7	3.2	9.0	21.0	4.75	4.60	4.90	5.00
400 lbs. sulfur	0	0	0	0	1.9	4.6	6.4	20.9	3.80	3.80	3.90	4.10
400 lbs. sulfur; 2,000 lbs. $CaCO_3$	0	5	200	395	2.7	5.9	11.3	36.0	4.90	4.85	4.70	5.00
2,000 lbs. $CaSO_4$; 2,000 lbs. $CaCO_3$	0	6	155	725	1.5	2.8	8.8	30.2	4.95	5.90	5.80	5.55

effect upon nodulation until the last series was harvested, when a decided increase was found.

No severe depression in growth was noted from any of the treatments. However, as shown by the dry weights, calcium carbonate stimulated growth, whereas calcium sulfate and sulfur retarded it. In general, this is the same influence exerted by these materials upon nodulation, but their effects upon growth were by no means so marked. The growth of plants could not be taken as a measure of nodulation.

There was an inverse relation between the acidity of the soil and nodulation. The treatments that increased acidity decreased nodulation and those that decreased acidity increased nodulation. The fact that calcium sulfate increased the acidity of the soil at all stages of growth probably accounts for the retardation and reduction of nodulation from its use. This conclusion is

supported by Albrecht (1), who recently reported that nodulation of soybeans failed on soils as acid as pH 5.0 even in the presence of sufficient calcium. The failure of nodulation in the sulfur-treated pots was also undoubtedly due to the high degree of soil acidity produced by the treatment.

Virgin Coxville fine sandy loam

The preceding experiment was repeated on July 13, 1933 with virgin Coxville fine sandy loam (pH 4.5). Treatments and results are shown in table 2.

In this experiment the first series was not torn down until 28 days after planting, at which time nodules had developed in all pots except those treated with single applications of calcium sulfate and sulfur. The nodulation data agree very closely with those obtained on the Norfolk soil. Calcium carbon-

TABLE 2

Nodulation and growth of peanuts and the pH of virgin Coxville fine sandy loam soil as influenced by calcium carbonate, calcium sulfate, and sulfur

Original pH 4.5. Planted July 13, 1933

TREATMENT PER ACRE	AVERAGE NUMBER OF NODULES PER POT (5 PLANTS)				AVERAGE DRY WEIGHT OF PLANTS PER POT (5 PLANTS)				pH OF SOIL			
	Days after planting											
	28	36	48	173	28	36	48	173	28	36	48	173
					gm.	*gm.*	*gm.*	*gm.*				
None	15	17	34	177	5.0	6.1	12.0	30.9	5.00	5.00	5.00	4.45
2,000 lbs. $CaCO_3$	93	156	154	228	6.6	8.9	16.7	29.5	5.80	5.50	5.35	4.85
2,000 lbs. $CaSO_4$	0	0	10	156	6.2	9.0	17.0	31.2	4.40	4.25	4.30	4.30
400 lbs. sulfur	0	0	0	0	5.1	6.5	13.3	30.0	3.85	3.75	4.20	4.20
400 lbs. sulfur; 2,000 lbs. $CaCO_3$	5	15	24	182	5.3	7.8	15.1	30.3	4.25	4.15	4.25	4.45
2,000 lbs. $CaSO_4$; 2,000 lbs. $CaCO_3$	25	37	62	216	6.0	11.5	18.6	29.3	4.80	4.65	4.90	4.45

ate stimulated and increased, calcium sulfate retarded and reduced, and sulfur prevented nodulation.

The dry weights of the plants gave no indication of the degree of nodulation at any stage of growth. At maturity all of the treatments had produced approximately the same amount of growth. The reaction of the Coxville soil was not influenced so much by the various treatments as was that of the Norfolk, undoubtedly because of the higher organic matter content and consequent greater buffer capacity of this soil. The general effect of the treatments on soil reaction was, however, the same on both soils. Calcium carbonate reduced, calcium sulfate slightly increased, and sulfur greatly increased acidity.

Cultivated and limed Norfolk sandy loam soil

It is evident that under the conditions of the two preceding experiments with virgin Norfolk (pH 5.3) and virgin Coxville (pH 4.5) soils, calcium car-

bonate stimulates, calcium sulfate retards and reduces, and sulfur prevents peanut nodulation. Practically all large type commercial peanuts, however, are grown on soils that have been previously limed and cultivated. For this reason a third experiment was made using a Norfolk sandy loam soil which had been in cultivation, with peanuts in rotation, for at least 50 years. When the experiment was set up August 24, 1932, the pH of the soil was 6.6, indicating that it had been limed. The results of this experiment are given in table 3.

Contrary to the results obtained with the two previous highly acid soils, calcium carbonate did not increase nodulation. At the last two counts the check pots had slightly more nodules than did those treated with calcium carbonate. As was the case with the other soils, calcium sulfate retarded and reduced nodulation, but its effect was not so marked. Even though this soil

TABLE 3

Nodulation and growth of peanuts and the pH of cultivated Norfolk sandy loam soil as influenced by calcium carbonate, calcium sulfate, and sulfur

Original pH 6.6. Planted September 24, 1932

TREATMENT PER ACRE	AVERAGE NUMBER OF NODULES PER POT (5 PLANTS)				AVERAGE DRY WEIGHT OF PLANTS PER POT (5 PLANTS)				pH OF SOIL			
	Days after planting											
	22	46	69	154	22	46	69	154	22	46	69	154
					gm.	*gm.*	*gm.*	*gm.*				
None	0	34	150	395	3.4	7.7	12.3	26.3	6.25	6.25	6.30	5.80
2,000 lbs. $CaCO_3$	0	36	142	377	3.9	7.1	12.8	28.0	7.20	7.40	7.30	6.50
2,000 lbs. $CaSO_4$	0	5	79	320	3.7	8.5	12.1	26.0	5.45	5.70	5.80	5.75
400 lbs. sulfur	0	0	0	0	3.5	6.2	12.1	24.8	4.50	4.00	4.75	5.10
400 lbs. sulfur; 2,000 lbs. $CaCO_3$	0	35	104	404	3.3	6.3	11.4	26.5	5.30	5.00	5.50	6.10
2,000 lbs. $CaSO_4$; 2,000 lbs. $CaCO_3$	0	33	114	414	4.0	6.9	12.5	23.8	6.90	7.20	7.15	6.30

had been limed to pH 6.6, 400 pounds of sulfur prevented nodulation of the peanuts at all stages of growth. These effects of sulfur upon nodulation are contrary to those reported by Duggar (5), who obtained increased nodulation from 200-pound applications. Further experiments should be made to determine the effect of varying amounts of sulfur on different soil types.

As in the other two experiments, there was no definite correlation between plant growth and nodulation. These results are further supported by field observations on various soil types. Examination of the plants in a large number of fields where the growth was poor showed the peanuts in many of them to be poorly nodulated, in others they were well nodulated, and in a very few fields there was excessive nodulation. An example of this latter condition is illustrated in plate 1, which shows excessive nodulation on the roots of inferior plants growing on a Portsmouth fine sandy loam (pH 5.5). The better

plants growing in the same field were not so heavily nodulated. The heavy nodulation, associated with weakened plants, may indicate that excessive nodulation is inducive of a disease-producing phenomena on the plant. A failure of Austrian winter peas apparently due to nodule bacteria has been reported by Leonard (8).

NODULATION AND GROWTH OF PEANUTS AND THE pH OF SOILS AS INFLUENCED BY CALCIUM CARBONATE

The fact that increased nodulation was obtained from applications of calcium carbonate on both the virgin Norfolk and virgin Coxville soils and that no increase was obtained on the limed Norfolk soils, indicates the importance of the amount of calcium carbonate and suggests a possible explanation for the conflicting results regarding the effect of calcium carbonate on the nodulation of legumes. The following experiment was made to study the effect of varying amounts of calcium carbonate upon the nodulation of peanuts.

Virgin Norfolk sandy loam soil

Eight series of seven pots each were set up, as in previous experiments, on July 12, 1934, with virgin Norfolk sandy loam soil (pH 5.0). One pot of each series was treated with the following amounts of calcium carbonate per acre: 2,000, 4,000, 6,000, 8,000, 12,000, and 16,000 pounds. The seventh pot was left untreated as a check. In table 4 are shown the results obtained at the four periods of growth.

Moderate applications of calcium carbonate increased nodulation, whereas heavy applications both retarded and reduced it. The reduction of nodulation was greatest with the heaviest applications of calcium carbonate. Although the nodulation curves are not identical, they exhibit the same trends at the four stages of growth, showing a maximum nodulation from moderate applications of calcium carbonate.

As pointed out by Jones and Tisdale (7), nodule count alone may not always be a true measure of the amount of nodulation. Photographs of the actual nodules from each treatment at the first and last counts are shown in plate 2.

No chlorosis or severe injury to growth developed from any of the treatments. There was a stimulation of growth from moderate applications of calcium carbonate which the very heavy applications reduced. The effect of the various treatments upon growth was not so marked as upon nodulation.

At all sampling periods, increasing amounts of calcium carbonate were attended by decreasing acidity or increasing alkalinity. Nodulation was very poor on all soils limed to pH 7.5 or above.

Virgin Coxville fine sandy loam soil

To determine whether or not heavy applications of calcium carbonate would also reduce nodulation of peanuts on a well-buffered soil high in organic

matter, the preceding experiment was repeated with virgin Coxville fine sandy loam soil (pH 4.5). The treatments and results are shown in table 5.

As was the case with the Norfolk soil, medium applications of calcium carbonate stimulated nodulation whereas heavy applications reduced it. The

TABLE 4

Nodulation and growth of peanuts and the pH of virgin Norfolk sandy loam soil as influenced by calcium carbonate

Original pH 5.0. Planted July 12, 1934

$CaCO_3$ applied per acre	Average number of nodules per pot (5 plants)				Average dry weight of plants per pot (5 plants)				pH of soil			
	Days after planting											
	35	57	94	146	35	57	94	146	35	57	94	146
pounds					*gm.*	*gm.*	*gm.*	*gm.*				
None	30	33	61	73	10.3	15.9	21.0	26.4	5.05	5.10	5.20	5.20
2,000	39	57	62	117	14.9	21.2	24.6	29.1	5.90	5.85	5.75	5.55
4,000	19	40	76	67	17.8	19.3	24.9	28.5	6.75	6.65	6.40	6.10
6,000	9	22	80	86	14.5	19.5	25.8	30.0	7.40	7.50	7.15	7.15
8,000	8	15	24	26	13.3	18.8	23.7	26.7	7.70	7.90	7.45	7.60
12,000	0	5	26	36	10.3	15.5	22.3	24.4	7.80	8.00	7.65	8.00
16,000	0	3	2	12	11.2	14.4	16.3	21.1	7.90	8.15	7.75	8.05

TABLE 5

Nodulation and growth of peanuts and the pH of virgin Coxville fine sandy loam soil as influenced by calcum carbonate

Original pH 4.5. Planted August 8, 1934

$CaCO_3$ applied per acre	Average number of nodules per pot (5 plants)				Average dry weight of plant per pot (5 plants)				pH of soil			
	Days after planting											
	31	63	91	115	31	63	91	115	31	63	91	115
pounds					*gm.*	*gm.*	*gm.*	*gm.*				
None	61	182	150	166	8.9	10.8	16.2	21.3	5.00	5.05	4.90	4.80
2,000	157	611	1,596	1,717	11.8	15.2	20.6	30.0	5.80	5.50	5.30	5.20
4,000	224	939	1,192	1,961	13.0	16.0	22.3	33.3	5.95	5.80	5.60	5.55
6,000	260	1,039	1,294	1,461	12.3	17.0	22.9	32.9	6.40	6.05	6.00	6.00
8,000	174	607	409	1,185	12.8	18.2	21.8	33.1	6.65	6.35	6.25	6.35
12,000	12	84	26	62	13.3	15.0	22.0	33.2	7.60	7.50	7.15	7.10
16,000	6	10	17	19	12.0	14.1	21.0	26.1	7.95	7.90	7.55	7.40

nodulation curves are in general very similar to those obtained on the Norfolk soil except that a much larger number of nodules was produced. Photographs of the actual nodules produced with each treatment at the first and last counts are shown in plate 3.

The use of calcium carbonate even at the excessive rate of 16,000 pounds per

acre improved the color and increased the dry weight of the plants over the checks. The greatest growth was produced by applications ranging from 4,000 to 12,000 pounds per acre. The pH of the Coxville soil was not increased so much by heavy application of calcium carbonate as was that of the Norfolk. As was the case with the Norfolk soil, however, applications above 6,000 pounds per acre materially reduced nodulation even though the pH was only slightly above 6.

The results offer an explanation for the conflicting reports as to the effect of calcium carbonate upon the nodulation of legumes. In these experiments calcium carbonate both increased and decreased peanut nodulation, the response depending upon the amount of calcium carbonate applied and that already present in the soil. Moderate amounts of calcium carbonate on unlimed soils increased, but similar applications on heavily limed soils and heavy applications on unlimed soils decreased, nodulation.

SUMMARY

Calcium carbonate applied at the rate of 2,000 pounds per acre to virgin Norfolk sandy loam (pH 5.3) and to virgin Coxville fine sandy loam (pH 4.5) increased nodulation of peanuts throughout the growing season. Similar applications to a cultivated Norfolk sandy loam that had been previously limed to pH 6.6 did not increase nodulation. On this soil during the latter part of the growing season there was a slight reduction of peanut nodulation from the use of calcium carbonate.

Calcium sulfate broadcast at the rate of 2,000 pounds per acre both delayed and reduced nodulation in all three soils.

Probably because of the high acidity produced, sulfur applied to the aforementioned soils, at the rate of 400 pounds per acre, prevented nodulation of peanuts at all stages of growth.

Combined applications of sulfur and calcium carbonate or calcium sulfate and calcium carbonate had little effect upon the nodulation of peanuts, except that at maturity the combination of calcium sulfate and calcium carbonate usually increased nodulation.

The growth of peanut plants, as measured by dry weight, could not be directly correlated with nodulation.

Calcium carbonate decreased, calcium sulfate slightly increased, and sulfur greatly increased, acidity of all the soils used. Probably because of its greater buffer capacity, the Coxville soil resisted reaction changes to a greater extent than either of the Norfolk soils.

Varying applications of calcium carbonate to virgin Norfolk and Coxville soils had quite different effects upon peanut nodulation. Many more nodules were produced on the Coxville than on the Norfolk soil, but the response to liming was similar on both. Moderate amounts of calcium carbonate stimulated and increased nodulation, but heavy applications retarded and reduced it.

These results offer an explanation for the conflicting reports as to the effect of lime upon legume nodulation.

REFERENCES

(1) ALBRECHT, WM. A. 1933 Inoculation of legumes as related to soil acidity. *Jour. Amer. Soc. Agron.* 25: 512–522.

(2) ALBRECHT, W. A., AND DAVIS, F. L. 1929 Physiological importance of calcium in legume inoculation. *Bot. Gaz.* 88: 310–321.

(3) ALBRECHT, W. A., AND DAVIS, F. L. 1929 Relation of calcium to the nodulation of soybeans on acid and neutral soils. *Soil Sci.* 28: 261–279.

(4) BOAS, F., AND MERKENSCHLAGER, F. 1923 Die Lupine als Objekt der Pflanzenforschung. Paul Parey, Berlin.

(5) DUGGAR, J. F. 1931 Effects of suphur and phosphates on nodule numbers. *Forty-second Ann. Rpt. Agr. Exp. Sta. Ala. Polytech. Inst.* 1931: 54.

(6) FELLERS, C. R. 1918 The effect of inoculation, fertilizer treatment and certain minerals on the yield, composition and nodule formation of soybeans. *Soil Sci.* 6: 81–129.

(7) JONES, F. R., AND TISDALE, W. B. 1921 Effect of soil temperature upon the development of nodules on the roots of certain legumes. *Jour. Agr. Res.* 12: 17–31.

(8) LEONARD, LEWIS T. 1930 A failure of Austrian winter peas apparently due to nodule bacteria. *Jour. Amer. Soc. Agron.* 22: 277–279.

(9) MERKENSCHLAGER, F. 1921 Die Chlorose der Lupine auf Kalkboden. *Fühlung's Landw. Ztg.* 70: 19–24.

(10) NELLER, J. R. 1926 Effect of sulphur upon nitrogen content of legumes. *Indus. and Engin. Chem.* 18: 72–73.

(11) PERKINS, A. T. 1924 The effect of several mineral fertilizers upon the nodulation of Virginia soybeans. *Soil Sci.* 17: 439–447.

(12) PERKINS, A. T. 1924 A note on the nodulation of soybeans. *Soil Sci.* 17: 449–456.

(13) PFEIFFER, T., UND SIMMERMACHER, W. 1919 Die Kalkfeindlichkeit der Lupine. *Landw. Vers. Sta.* 93: 1–47.

(14) PITZ, W. 1916 Effect of elemental sulfur and of calcium sulfate on certain of the higher and lower forms of plant life. *Jour. Agr. Res.* 5: 771–780.

(15) PRUCHA, M. J. 1915 Physiological studies of Bacillus radicicola of Canada field pea. *N. Y. (Cornell) Agr. Col. Mem.* 5: 1–83.

(16) REIMER, F. C., AND TARTAR, H. V. 1919 Sulfur as a fertilizer for alfalfa in southern Oregon. Ore. Agr. Exp. Sta. Bul. 163.

(17) SCANLAN, R. W. 1928 Calcium as a factor in soybean inoculation. *Soil Sci.* 25: 313–325.

(18) WILSON, J. K. 1917 Physiological studies of the Bacillus radicicola of the soybean (Soja Max Piper) and of the factors influencing nodule production. *N. Y. (Cornell) Agr. Exp. Sta. Bul.* 386: 369–413.

PLATE 1

EXCESSIVE NODULATION ON THE ROOTS OF INFERIOR PEANUTS GROWN ON PORTSMOUTH FINE SANDY LOAM (pH 5.5)

PLATE 2

NODULATION OF PEANUTS IN VIRGIN NORFOLK SANDY LOAM (pH 5.0) AS AFFECTED BY APPLICATIONS OF CALCIUM CARBONATE

FIG. 1. Nodules per pot of five plants 35 days after planting. *A*, no calcium carbonate; *B*, 2,000; *C*, 4,000; *D*, 6,000; *E*, 8,000; *F*, 12,000; and *G*, 16,000 pounds calcium carbonate per acre.

FIG. 2. Nodules per pot of five plants at maturity, 146 days after planting. *A*, no calcium carbonate; *B*, 2,000; *C*, 4,000; *D*, 6,000; *E*, 8,000; *F*, 12,000; and *G*, 16,000 pounds calcium carbonate per acre.

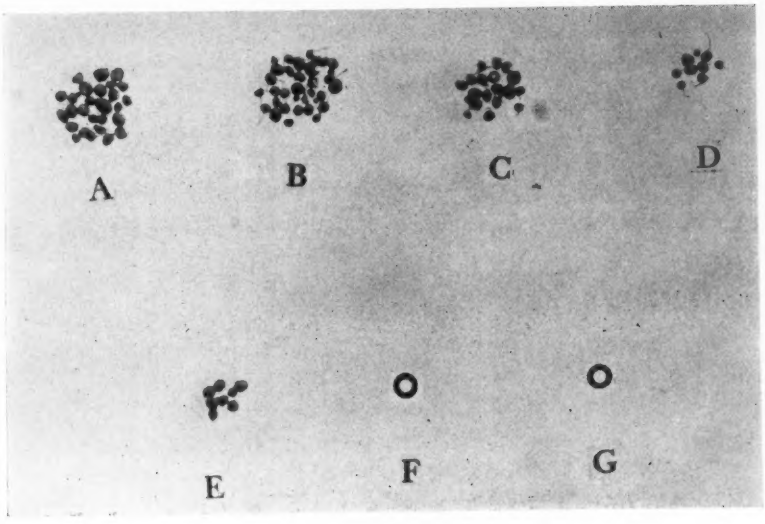


FIG. 1

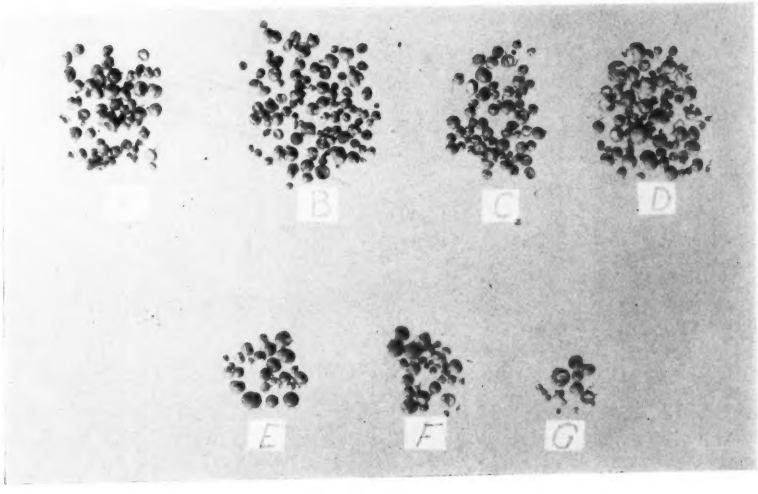


FIG. 2

PLATE 3

NODULATION OF PEANUTS IN VIRGIN COXVILLE FINE SANDY LOAM (pH 4.5) AS AFFECTED BY APPLICATIONS OF CALCIUM CARBONATE

FIG. 1. Nodules per pot of five plants 31 days after planting. *A*, no calcium carbonate; *B*, 2,000; *C*, 4,000; *D*, 6,000; *E*, 8,000; *F*, 12,000; and *G*, 16,000 pounds calcium carbonate per acre.

FIG. 2. Nodules per pot of five plants at maturity, 115 days after planting. *A*, no calcium carbonate; *B*, 2,000; *C*, 4,000; *D*, 6,000; *E*, 8,000; *F*, 12,000; and *G*, 16,000 pounds calcium carbonate per acre.

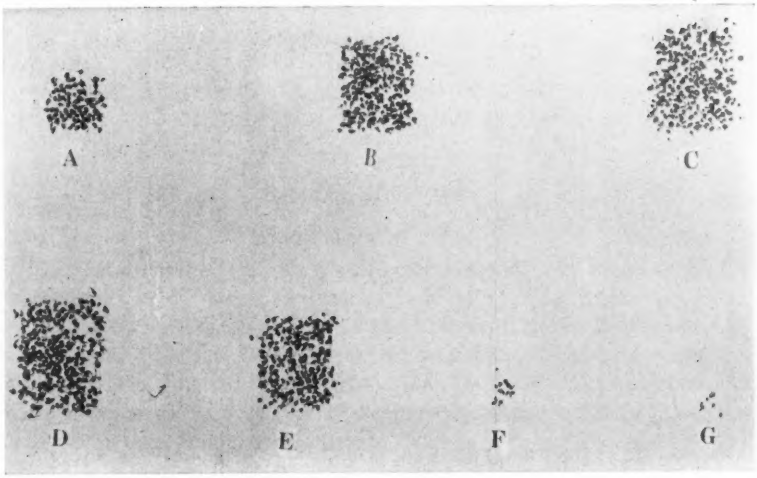


FIG. 1

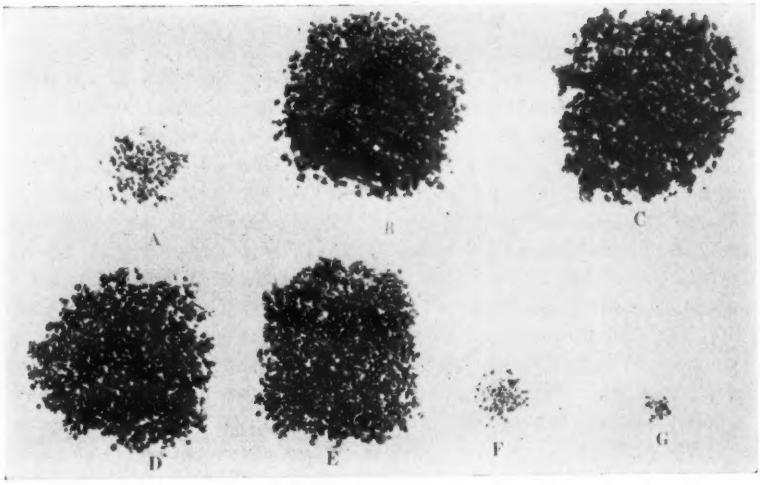


FIG. 2

THE RELATION OF SOIL EROSION TO CERTAIN INHERENT SOIL PROPERTIES[1]

J. F. LUTZ[2]

North Carolina State College

Received for publication April 5, 1935

It has been observed that some soils erode easily whereas others under the same conditions of rainfall, vegetation, and topography erode very little, apparently because of differences in their physical or chemical properties. Some very valuable data on erosion control with different systems of management have been obtained (4, 13, 25), but our knowledge of the physical and chemical properties of soils which influence erosion has not been materially increased by these field experiments.

It is the object of this paper to present the results of a laboratory study of the physical and chemical properties of several soils that are known to vary in their erosiveness, and to show that certain of these properties play an important rôle in determining the susceptibility of a soil to erosion.

PROPERTIES OF THE SOIL INFLUENCING EROSION

The amount of erosion depends partly upon the amount and the velocity of run-off water and partly upon soil properties. The amount of run-off from any given rain depends upon the rate of water absorption and the permeability of the soil. The permeability of a soil profile is determined by the rate of percolation through the least permeable layer, which in most upland soils is the B horizon. Janota (14) found that soils with a total pore volume of less than 40 per cent were impermeable. Baver (6) observed that a soil with 5.9 per cent of air pores at a depth of 16 to 20 inches was well drained, but one with an air capacity of 2 per cent at the same depth was rather poorly drained. Slater and Byers (26) found that the rate of percolation of water through a number of soil cores was correlated with the silt content of the soil. Antipov-Karatajev (3) reported that the rate of filtration was a function of the colloid content of the soil and that the filtration velocity through soils depended upon the nature of the exchangeable ions present. The rate of filtration followed the series: $Fe > Ca > Mg > NH_4 > Na$.

Middleton (23) found that the best indexes to erosiveness were the dispersion ratio, the ratio of colloid content to moisture equivalent, the erosion ratio,

[1] A part of a thesis presented to the Graduate School of the University of Missouri in partial fulfilment of the requirements for the degree of doctor of philosophy.

[2] Assistant professor of soils, North Carolina State College. The author is indebted to Dr. L. D. Baver for his many helpful suggestions during this investigation.

and the silica-sesquioxide ratio. Soils with a low silica-sesquioxide ratio were difficult to disperse.

Soils differ in the amount of material eroded per unit of run-off water. Carefully controlled experiments (25) have shown that the amount of erosion per cubic foot of run-off decreased from 0.881 pound to 0.477 pound as a result of plowing under organic matter. Baver and Rhoades (8) have shown that soils high in organic matter contain from 15 to 30 per cent more granules than those low in organic matter and that the granules are three times more stable when shaken with water for 100 minutes. Jenny (16) found that cultivation for 40 years, as compared with a virgin prairie, caused a 38 per cent decrease in organic matter and a 28 per cent decrease in sand-size granules. Burr and Russel (12) report that the addition of organic matter increased the porosity of the soil and the stability of the granules. Data given by Middleton et al. (24) indicate an inverse relation between the organic matter content and the erosion and dispersion ratios.

Mechanical and aggregate analyses

The Iredell sandy clay loam and the Davidson clay were selected for studying the physical properties of soils influencing erosion, because field observations have shown that the Iredell is an erosive soil and the Davidson a comparatively non-erosive one. There is a higher percentage of clay in all horizons of the Davidson than in the corresponding horizons of the Iredell (19). This is especially true in the A horizon. This horizon of the Iredell contains more than twice as much sand and 1.5 times more sand plus silt than the same horizon of the Davidson. Such a difference in texture might suggest that the Iredell was less erosive than the Davidson, especially since the B horizon of the Davidson contains more clay than the B layer of the Iredell. There is, however, a marked difference in the physical condition of the clay. The Iredell B horizon is a brownish yellow, heavy, plastic, sticky, and impervious clay when wet, which shrinks, cracks, and becomes very hard when dry. The Davidson, on the other hand, is a dark red, heavy but friable clay which breaks into large lumps that are easily crumbled into small fragments or granules.

The difference in the character of the B horizon of these two soils is shown by the extent to which they are aggregated. Granulation was measured by the Kopecky type of elutriator (8). The soils were dried just enough so they could be gently rubbed through a 2-mm. sieve, and were then placed in the elutriator without further treatment. In order to obtain ultimate dispersion they were shaken over night in a reciprocal shaker after treatment with a dispersing agent. The Iredell soil was dispersed with $Na_2C_2O_4$. The Davidson, however, flocculated in the presence of $Na_2C_2O_4$; consequently, NaOH was used as the peptizing agent. Although NaOH effectively dispersed the natural Davidson soil, the electrodialyzed colloid was not dispersed by any concentration of base. Apparently, the small amount of Cl ions in the natural soil aided in obtaining dispersion. A considerable quantity of Cl ions was found in the anode chamber during electrodialysis.

A careful analysis of figures 1 and 2 shows several very important facts concerning the extent and character of aggregation of the A and B horizons of the profiles. If the total percentage of aggregates in the soil, as represented by the cross-hatched portion of the graphs, is considered, it is noted that both

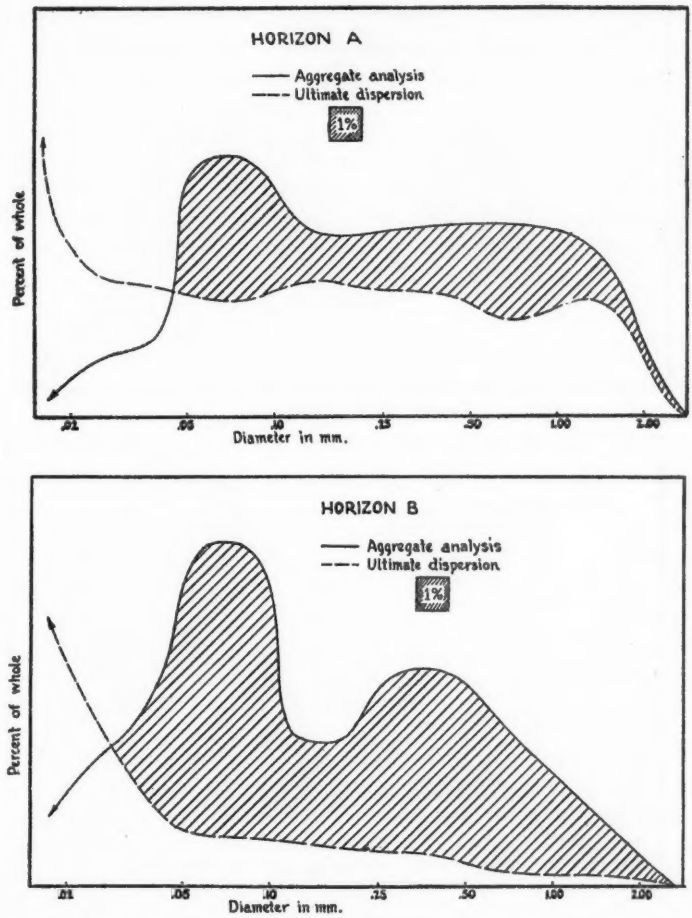


FIG. 1. SIZE-FREQUENCY DISTRIBUTION CURVE OF IREDELL SANDY CLAY LOAM WITH AND WITHOUT DISPERSION

soils are rather highly granulated. Since the curves for ultimate dispersion and aggregate analysis cross at about 0.05 mm., this value was chosen as the lower limit of aggregate size in calculating the total degree of aggregation.

The graphs show that the Davidson contains 15 to 20 per cent more aggre-

gates in each horizon than the Iredell. Nevertheless, there is a relatively high content of total aggregates in the Iredell. The B horizon[3] contains 64 per cent of granules, which is only 9 per cent less than the Davidson. In the Davidson

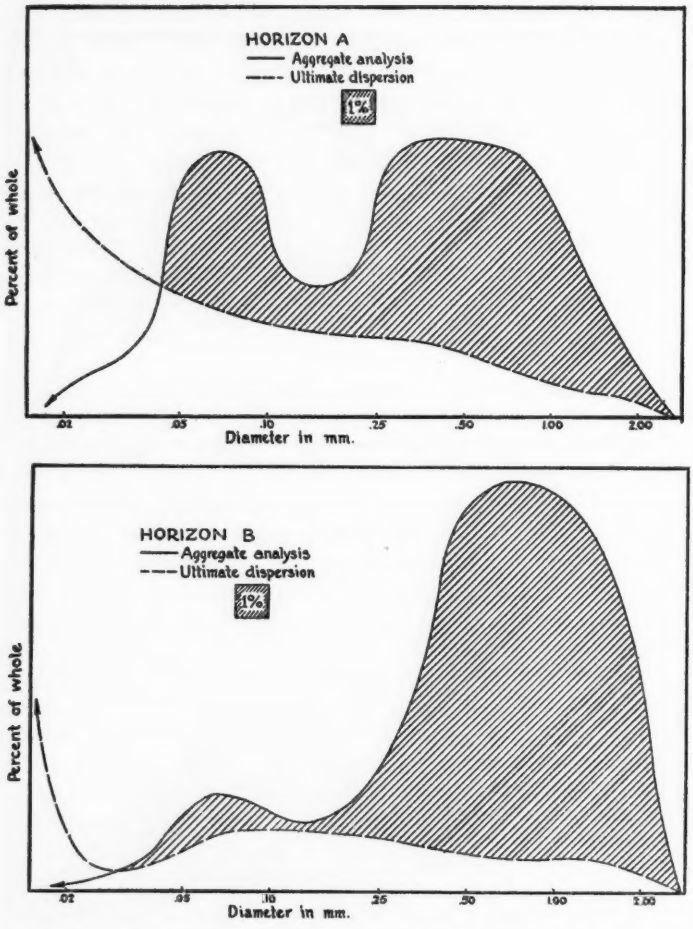


FIG. 2. SIZE-FREQUENCY DISTRIBUTION CURVE OF DAVIDSON CLAY WITH AND WITHOUT DISPERSION

91.9 per cent of the silt and clay is aggregated; in the Iredell only 74.2 per cent is in the form of granules larger in size than silt.

Neither the percentage of silt and clay aggregated nor the percentage of total

[3] Since the B horizon limits the permeability of the soil profile all discussion of aggregation will be limited to this layer except where otherwise indicated.

aggregates in the soil indicates the real differences between the two soils. If the B horizons are considered, it is observed that only 34.9 per cent of the silt and clay in the Iredell is aggregated into aggregates larger than 0.25 mm., whereas in the Davidson 87 per cent of the corresponding mechanical separates is in the form of large granules (> 0.25 mm. in diameter). In other words, 149 per cent more of the silt and clay in the Davidson has been aggregated into large stable granules. Of the total aggregates present (> 0.05 mm.) 94.6 per cent are larger than 0.25 mm. in diameter in the Davidson; in the Iredell only 46.9 per cent are of the larger size. An analysis of the entire profile shows that there is a more or less constant amount of aggregates in the Iredell from the surface downward. The Davidson, however, contains a higher percentage of large granules in the B horizon than in the A and C layers.

Examination of the granules with a wide field binocular microscope shows that the character of the aggregates in these soils is markedly different. The

TABLE 1

Dispersion and erosion ratios

SOIL TYPE AND HORIZON	MIDDLETON METHOD		AGGREGATE METHOD*	
	Dispersion ratio	Erosion ratio	Dispersion ratio	Erosion ratio
Iredell A	16.5	14.1	34.0	29.1
Iredell B	12.1	9.5	25.8	20.2
Iredell C	34.2	32.2	40.0	27.8
Davidson A	3.6	2.3	17.1	10.8
Davidson B	2.6	1.2	8.5	4.0
Davidson C	3.6	2.9	17.7	14.4

* In this method the dispersion ratio is = per cent silt + clay separated by aggregate analysis divided by total per cent silt + clay × 100. The erosion ratio is this dispersion ratio divided by the colloid: moisture equivalent ratio.

Iredell aggregates appear to consist of a sand grain which is coated with a layer of silt and clay. These sand, silt, and clay particles which make up the secondary particles are held together by some cementing material, probably gelatinous silica. This same material cements the aggregates together, forming an impermeable soil layer.[4] When pressure is applied with the fingers to a cluster of these aggregates, they mold like putty except for the coarse, inner particle. They might be classed as "stone-fruit-like" aggregates. However, in the light of a recent classification of soil structure by Baver (7) these secondary particles are not true granules and probably should be called "fragments."

The Davidson aggregates are composed of groups of smaller aggregates that crumble under pressure into smaller granules. They appear distinctly porous

[4] The swelling of the colloids undoubtedly plays an important rôle in the permeability of this layer. This will be discussed later.

under the microscope. They are true granules and may be referred to as the "pop-corn ball" type of aggregate.

Dispersion and erosion ratios

The dispersion and erosion ratios by the Middleton method (23) agree somewhat with the aggregate analysis data as shown by table 1. The differences between the two soils are greater, however, than in the data reported by Middleton, the greater difference being shown by the erosion ratio. Because the erosion ratio is a more or less empirical factor it is difficult to visualize why any relationship should exist between the colloid: moisture equivalent ratio and the erosiveness of a soil. The dispersion ratio should give a better index of the erosiveness of a soil. Consequently, it will receive the greater emphasis in this discussion. The dispersion ratio as determined by Middleton is a measure of the stability of soil aggregates under the influence of moving water.

Since an aggregate analysis measures essentially the same effects, the data thus obtained were used to calculate this ratio. The values were always higher than by the Middleton method because the aggregate analysis caused a greater dispersion of the secondary particles due to the washing out of soluble flocculating electrolytes that are always present in the Middleton method. Moreover, some silt and clay are probably flocculated orthokinetically when using sedimentation methods; in an aggregate analysis such a possibility is eliminated.

PROPERTIES OF THE COLLOIDS AFFECTING EROSION

Most of the physical and chemical properties of soils are dependent upon or associated with the colloidal fraction. In this investigation the physical properties of soils affecting erosion are interpreted in the light of a series of data upon the physicochemical properties of the extracted colloids when treated with various cations.

Chemical composition of the colloids

The Davidson just barely is a lateritic soil (19) if a SiO_2–Al_2O_3 ratio of 2 or less in the colloid fraction, as suggested by Harrassowitz, is used as the criterion for lateritization. The Iredell with a ratio of 2.49 is intermediate between the Davidson and the Putnam, which has a SiO_2–Al_2O_3 ratio of 3.02 (11). Apparently the impervious nature of the Iredell profile has not permitted as rapid weathering as the more permeable Davidson soil. The decrease in the SiO_2–Al_2O_3 ratio from the Putnam to the Davidson is accompanied by a decrease in the total cationic exchange capacity of the complex from 60 to 12 m.e. per 100 gm. of colloid. The magnitude of the charge on the particles has also been shown to decrease with the silica-sesquioxide ratio (1, 2, 20). Since the intensity of the charge of the colloidal particles is considered one of the main factors influencing the stability of colloidal suspensions, soils such as the Davidson should be expected to flocculate; soils with a ratio as high as the Putnam (3.02) should be stable.

Stability of colloidal clay suspensions

It was observed throughout this study that all colloidal suspensions of the Davidson were flocculated irrespective of the nature of the exchangeable cations on the complex. Only the H-, Ca-, and Ba-suspensions of the Iredell and Putnam were flocculated; these suspensions precipitated very slowly as compared with the Davidson soils. The flocculation time (table 2) was considered as that moment when a thin layer of supernatant liquid could be observed

TABLE 2

The relation of different cations to the reaction, charge, and flocculation of several colloidal clays

COLLOID AND TREATMENT	pH	ZETA POTENTIAL*	MIGRATION VELOCITY, MICRONS PER SEC. 1 VOLT PER CM.	FLOCCULATION TIME	VOLUME OF FLOC. AFTER 24 HOURS
		millivolts			*cc. per gm.*
H—Iredell	4.04	39.0	3.07	4 min.	5.2
Li—Iredell	6.91	42.1	3.31	Stable	
Na—Iredell	7.29	41.2	3.24	Stable	
K—Iredell	6.91	38.9	3.06	Stable	
Ca—Iredell	6.59	35.8	2.82	5 min.	6.0
Ba—Iredell	6.58	29.7	2.34	6 hrs.	7.2
H—Davidson	4.50	36.8	2.90	1 min.	4.0
Li—Davidson	6.85	40.5	3.19	2 min.	5.2
Na—Davidson	7.31	39.4	3.10	2 min.	5.4
K—Davidson	6.92	37.9	2.98	2 min.	5.4
Ca—Davidson	7.13	36.3	2.86	1 min.	3.0
Ba—Davidson	7.11	35.3	2.78	1 min.	3.2
H—Putnam	4.10	36.3	2.86	All stable after 24 hours; H, Ba, and Ca flocculated in about three days	
Li—Putnam	7.61	40.3	3.17		
Na—Putnam	7.66	38.5	3.03		
K—Putnam	7.32	38.7	3.05		
Ca—Putnam	6.96	35.0	2.75		
Ba—Putnam	6.86	32.6	2.56		

* Credit is due Mr. R. F. Reitmeier for making the cataphoretic measurements.

above the suspension. The volume per gram of clay in the flocculated systems, the pH, and the zeta-potential and migration velocity of the colloidal particles are tabulated in table 2.

An analysis of these data and of associated factors throws much light on the relation of charge and hydration to the flocculation of colloidal clay suspensions. Kruyt (17) points out that the two factors influencing the stability of colloidal suspensions are the charge and the hydration of the dispersed particles. Wiegner (27) and Bradfield (10) consider that the magnitude of the charge of clay particles is due to the anionic nature (inner layer) of the colloidal complex and

that the potential increases or decreases directly with the extent of dissociation of cations from the colloidal surface.

Mattson (20), Anderson (1), and Anderson and Mattson (2) have shown that the charge and the exchange capacity of the colloid vary directly with the silica-sesquioxide ratio.

The charge of the Iredell, Davidson, and Putnam colloids was determined ultramicroscopically by means of a modification of the Tuorila cell (5). Suspensions of 0.0001 per cent by weight were used (19). The zeta-potential was calculated by the Helmholtz-Perrin equation, using the factor 4. The results with the Putnam sols agree with those reported by Baver (5). The potentials follow the ionic series: Li > Na = K > H > Ca > Ba. The Li-, Na-, and K- Putnam sols were all stable, but the H-, Ba-, and Ca- systems flocculated very slowly. The intensity of the charge of the lateritic Davidson and that of the semi-lateritic Iredell colloids do not agree, however, with the data of Mattson, Anderson, and Anderson and Mattson. From the data of these investigators and others (10, 27) these colloids, especially the Davidson, would naturally be expected to have a lower negative charge than the Putnam. The negative potentials of all Iredell and Davidson sols were higher than those of the Putnam with the exception of the Ba-Iredell and the K-Davidson. It is difficult to explain these striking differences in the light of existing information. However, certain facts have been observed which may be used to explain partially these puzzling results.

The large differences in the hydration of the Davidson, Iredell, and Putnam colloids may affect the relative migration velocities of the particles. The method of calculating the zeta-potential from the Helmholtz-Perrin equation does not take into consideration the hydration of the particles. The data in table 3 show that the Putnam systems are more highly hydrated than those of the Iredell; the Davidson is not appreciably hydrated. The presence of a water shell around the particle might decrease the effectiveness of the "active points" on the surface of the colloid. Consequently, even though the Putnam colloid has five times as many "active points" (evidenced by its higher exchange capacity) as the Davidson, the high hydration of the Putnam might directly or indirectly impede the movement of the particles in an electric field.

Secondly, symmetry value (15) determinations show that the H ions are more easily replaced from the Davidson and Iredell colloids than from the Putnam. The symmetry values are:

	Putnam	*Iredell*	*Davidson*
With same clay concentration (KCl concentration = exchangeable H-ions) *per cent*.....	12.33	18.85	20.0
With same KCl concentration (same as exchangeable H ions) *per cent*.....	13.52	16.66	20.33

The values for the Putnam colloid agree very closely with those reported by Jenny (15) if allowance is made for slight differences in the clay concentrations. These results show that about 20 per cent of the replaceable H ions on the

Davidson colloid and only about 13 per cent of those on the Putnam colloid are exchanged by K ions at the symmetry concentration. In other words, the H ions on the Davidson are more active than those on the Putnam when considered on the basis of the total quantity present. Determinations of the pH values of the electrodialyzed colloids also indicate that the clay acids in the Davidson and Iredell are more highly "dissociated" than the Putnam acid clay. Calculations based upon the pH values show that 1.26, 1.24, and 0.66 per cent of the total H ions present are "dissociated" in the Davidson, Iredell, and Putnam clays, respectively. If the "dissociation" of the Davidson is taken as 100, the Putnam and Iredell clay acids are 52.4 and 98.4 per cent "ionized," respectively. The symmetry values show that the exchangeable ions on the Putnam and Iredell colloids are only 61.4 and 94.4 per cent, respectively, as easily replaced as those on the Davidson. The two methods, therefore, give similar results and suggest that the potential of the Davidson colloid may be similar to the Putnam because of a greater activity of the exchangeable ions.

Thirdly, Lottermoser and Riedel (18) have shown that dilution of the positive Al_2O_3, Fe_2O_3, Cr_2O_3, and ThO_2 sols caused a reversal of charge; the sols were negatively charged in dilute concentrations. They attribute these results to an increase in dissociation with dilution and state that dilution and dialysis have the same effect on the intensity of the charge of colloidal particles. The sols used in the present investigation were rather dilute (0.0001 per cent) and, in the light of the dilution effect reported by Lottermoser and Riedel, the Davidson and Iredell colloids may exhibit a higher negative charge than would be expected in more concentrated systems.

The flocculation of the Davidson sols irrespective of the amount and nature of cations present, and in spite of a high zeta-potential, indicates that hydration is probably a more important factor influencing the stability of colloidal clay suspensions than is usually considered. The non-hydrated condition of lateritic soils such as the Davidson allows them to maintain a high state of granulation which, because of their inability to become hydrated, is not destroyed by the influence of water. Semi-lateritic and non-lateritic colloids such as the Iredell and Putnam are capable of becoming rather highly hydrated and, therefore probably form very unstable secondary particles except under extreme dehydration or in the presence of cementing materials such as organic matter. These results on the relative stability of the Iredell and Davidson colloids point out quite distinctly the reasons for the high degree of aggregation of the Davidson and the resistance of its granules to the dispersing action of run-off water.

Hydration of colloidal clays

Several methods of measuring the degree of hydration of soil colloids may be used, depending on whether the colloid is in the dry state or in suspension. Hydration can be determined by measuring the liquid intake of dry colloids (28). The significance of this type of water will be discussed in connection

with the swelling data. The relative hydration of different sols may be indirectly determined by calculations from viscosity data.

The water associated with the clay, as calculated from viscosity measurements, may consist either of a water "hull" around the clay particles (if completely dispersed) or of occluded water that is mechanically held between the

TABLE 3

The relation of exchangeable cations to the viscosity and swelling of several colloidal clays

COLLOID AND TREATMENT	RELATIVE VISCOSITY	WATER OF HYDRATION*	LIQUID INTAKE		
			H_2O	C_6H_6	Swelling
		cc. per gm.	*cc. per gm.*	*cc. per gm.*	*cc. per gm.*
H—Bentonite	7.00	35.00	3.77	1.45	2.32
Li—Bentonite	4.41	28.41	13.45	1.35	12.10
Na—Bentonite	3.41	24.11	12.27	1.20	11.07
K—Bentonite	2.92	21.31	9.76	1.20	8.56
Ca—Bentonite	3.42	24.16	4.00	1.50	2.50
Ba—Bentonite	6.51	33.96	3.90	1.40	2.50
H—Putnam	1.21	3.49	1.80	0.98	0.82
Li—Putnam	1.23	3.84	6.51	1.25	5.26
Na—Putnam	1.25	4.19	5.45	1.25	4.20
K—Putnam	1.24	4.04	1.46	0.96	0.50
Ca—Putnam	1.19	3.19	1.90	1.00	0.90
Ba—Putnam	1.20	3.34	1.74	0.90	0.84
H—Iredell	1.51	8.08	1.69	1.46	0.23
Li—Iredell	1.17	2.83	1.78	1.36	0.42
Na—Iredell	1.16	2.63	1.98	1.38	0.60
K-Iredell	1.18	2.98	1.53	1.51	0.02
Ca—Iredell	1.27	4.53	1.92	1.62	0.30
Ba—Iredell	1.26	4.33	1.86	1.50	0.36
H—Davidson	1.41	6.66	2.26	2.41	−0.15†
Li—Davidson	1.58	9.01	2.02	2.18	−0.16
Na—Davidson	1.51	8.06	1.90	2.08	−0.18
K—Davidson	1.77	11.41	1.93	2.35	−0.42
Ca—Davidson	1.31	5.11	1.94	2.22	−0.28
Ba—Davidson	1.35	5.76	2.08	2.43	−0.35

* Calculated by the Mark and Meyer equation.

† The lower intake of water is due to a settling of the fluffy, dry colloid when wetted.

particles in a flocculated system. The thickness of the water hull undoubtedly is related to (*a*) the adsorptive capacity of the colloid for water molecules as affected by the nature of the inner layer and the amount and kind of exchangeable cations in the outer layer of the colloid and (*b*) the concentration of the sol. The amount of occluded water depends largely upon the degree of flocculation of the system, but is probably affected also by the hydration of the

flocculating cation. In systems such as the highly flocculated Davidson sols most of the water is probably held as occluded water. In thoroughly dispersed systems most of the hydration water is present as a shell around the colloidal particle. Calculations of the hydration water were made according to the Meyer and Mark modification (22) of the Einstein equation (17).

The data in table 3 show that the various cations do not affect the viscosity of different clays in the same order except that the viscosity of the H-, Ba-, and Ca- sols always ranked in the order named. The high content of water associated with a gram of clay in the Davidson systems and in the H-, Ca-, and Ba- Iredell sols is due to water of occlusion, since all of these sols were completely flocculated. The H-, Ba-, and Ca- Putnam sols flocculated so slowly that the amount of occluded water was probably very small. The data also show that the Li-, Na-, and K- Putnam colloids are about twice as highly hydrated as the corresponding Iredell systems. The chemical nature of the colloidal particle is undoubtedly responsible for these differences. Apparently, the inner layer of the Putnam colloid has a relatively high polarizing enect on the water molecules. All bentonite sols were extremely viscous indicating that the chemical nature of the alumino-silicate particle must have a pronounced effect upon the hydration of the particle. Bentonite has an exchange capacity of about 90 m.e. per 100 gm. of colloid.

Swelling of soil colloids.—Numerous investigators have noted a certain relationship between swelling and other properties of soil colloids. Bennett (9) observed that soils with a low silica-sesquioxide ratio were more friable, permeable, and resistant to erosion than those with a high ratio, and that the friable soils showed no visible swelling or shrinking even at extreme moisture variations. Soils with a high SiO_2-R_2O_3 ratio were subject to wide changes in volume during drying or wetting. Anderson (1) found that swelling increased with the SiO_2-R_2O_3 ratio and that Na-saturated clay swelled about twice as much as K- clay. Additions of Ca ions to the Na- clay decreased the amount of swelling. Mattson (21) studied the effect of adsorbed cations on the swelling of soils and found that swelling decreased according to the ionic series: Na > K > Ca > Mg > H > methylene blue. Winterkorn and Baver (28) have reported that the total amount of water taken up by the colloidal clays increased with the SiO_2-R_2O_3 ratio. They also show that water intake extends over a longer period of time in soils with a high SiO_2-R_2O_3 ratio.

The swelling data in table 3 were obtained by the method of Winterkorn and Baver (28). The order of swelling of the different clays is: Bentonite[5] > Putnam[5] > Iredell > Davidson, with the latter exhibiting no swelling. The SiO_2-R_2O_3 ratios of these colloids decrease in the same order. Baver and Winterkorn[6] have shown that the swelling of any given colloid varies with the

[5] The swelling data on the bentonite and Putnam colloids were obtained by H. F. Winterkorn (28).

[6] Baver, L. D., and Winterkorn, H. F., University of Missouri, unpublished data compiled, 1934.

nature of the cations on the exchange complex. In bentonite swelling followed the ionic series: Li > Na > K > Ca = Ba > H; in Putnam clay the series was: Li > Na > Ca > Ba > H > K; in Iredell the series was: Na > Li > Ba > Ca > H > K; the Davidson exhibited no swelling irrespective of the nature of the exchangeable cations present. The low swelling of the K-saturated Iredell colloids confirms the results of Baver and Winterkorn[6] with other K-saturated clays. Moreover, their observations concerning the relative differences between the swelling of Ca- and H- saturated systems are confirmed by the behavior of the Ca- and H- Iredell colloids. The practical significance of these results is mentioned in the general discussion of this paper. The data distinctly point out that the hydration of clays is to a great extent determined by the chemical nature of the clay particle and that colloidal clays behave differently in their swelling from bentonite.

The swelling data partly explain the differences between the rate of percolation of water through the Iredell and Davidson soils and the extent to which the soils are aggregated into stable granules.

Inasmuch as the Davidson colloid does not swell in the presence of water one should expect the soil to have a relatively high permeability for water; the aggregates should be more stable than those secondary particles that increase in volume when wetted. Consequently, on the basis of hydration alone, the Davidson soil should be more resistant to the erosive action of water than the Iredell.

Permeability of colloidal clay membranes

The permeability of a soil profile is controlled largely by the amount and state of dispersity of the colloidal material present. Many soils with a highly colloidal B-horizon such as the Iredell and Putnam, are only slightly permeable to water; other soils, however, such as the Davidson with just as high a colloid content are extremely permeable: Bennett (9) observed that certain lateritic soils with a very high clay content were decidedly permeable to water and could be cultivated soon after heavy rains; these permeable clay soils apparently were not highly hydrated. Antipov-Karatajev (3) observed that soils saturated with iron were very permeable. Baver (5) studied the rate of ultrafiltration through Na- and Ca-colloidal clay membranes and calculated the size of the pores in the membranes on the basis of the rate of filtration. The pores in the Ca- clay membranes were found to be 8.3 times larger than those in the Na- clay.

In the present investigation the permeabilities of colloidal clay membranes[7] of the Iredell, Davidson, Putnam, and Bentonite colloids, when treated with various cations, were studied.

The data (fig. 3 to 5 inclusive) show a segregation of the curves into two groups as far as the effects of the exchangeable cations are concerned. The

[7] See (19) for method of preparation of membranes.

one group contains the Li-, Na-, and K- sols, and the other, the H-, Ba-, and Ca systems. This division is very pronounced with the Iredell. Apparently, the rate of ultrafiltration is related to the degree of flocculation, the more flocculated systems being more permeable than the dispersed. Since all of the Davidson sols are flocculated, the rates of filtration are somewhat similar. Qualitative tests of the rate of filtration through a glass filter under a pressure of one atmosphere showed that all the Davidson systems and the H-, Ba-, and Ca- Iredell sols flocculated and that the volumes of the floccules formed remained practically constant until the supernatant liquid had been removed. The volume of the floc then decreased under the applied pressure, resulting in the squeezing out of occluded water from the loosely held floccules. The filtra-

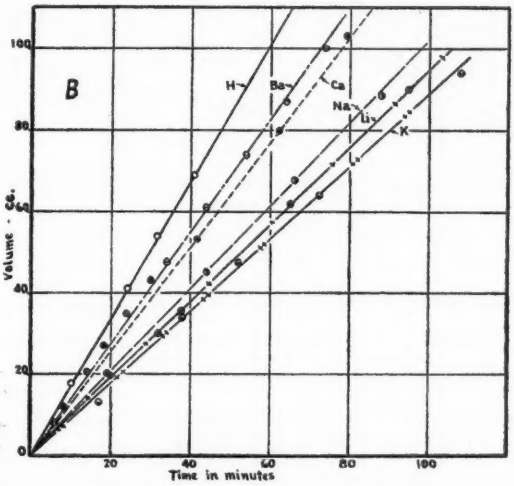


FIG. 3. EFFECT OF DIFFERENT CATIONS UPON THE PERMEABILITY OF DAVIDSON CLAY MEMBRANES

tion up to this point apparently proceeded more or less as a water displacement. This resulted in a constant rate of filtration until the last few cubic centimeters of intermicellar liquid were removed. Packing of the clay membrane by removal of occluded water then caused a decrease in the rate of percolation in the more hydrated systems such as the Ba- and H-Iredell; in the weakly hydrated systems such as the Davidson the rate of filtration remained constant until all of the intermicellar liquid had been removed.

The permeability of the membranes formed from 1 gm. of clay or bentonite follows the definite order of H > Ba > Ca which is the same as that of their relative viscosity. In the Iredell and Putnam colloids and in the bentonite, the order of the alkali cations was K > Na > Li; in the Davidson the order was Na > Li > K. No definite relationship existed between the swelling and

the permeability of the various clay membranes if all systems are considered. If, however, only the H-, Ca-, and Ba- systems are considered, permeability

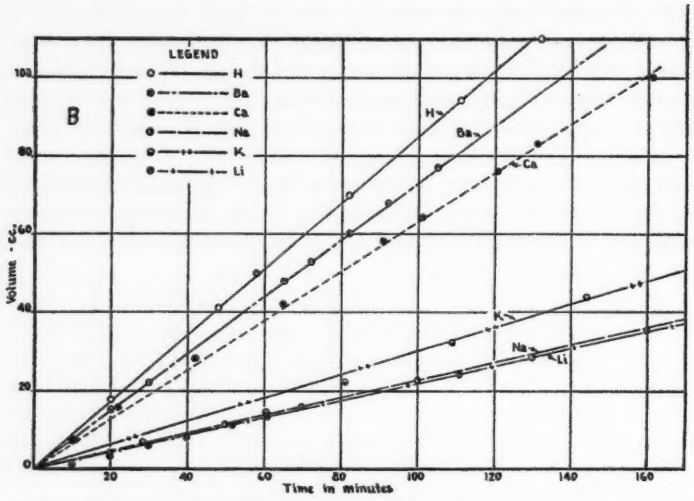


FIG. 4. EFFECT OF DIFFERENT CATIONS UPON THE PERMEABILITY OF IREDELL CLAY MEMBRANES

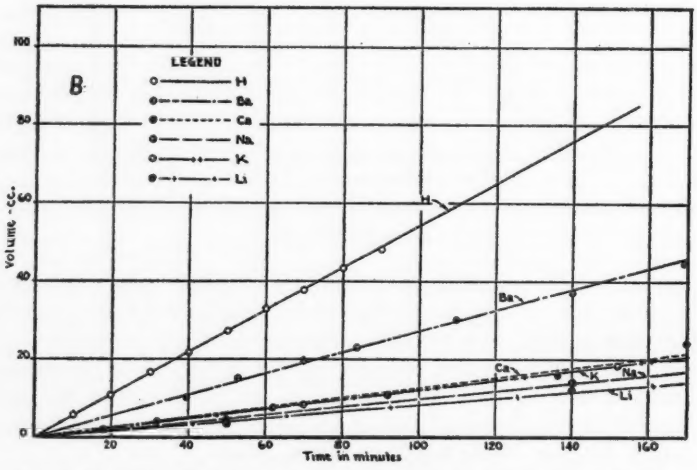


FIG. 5. EFFECT OF DIFFERENT CATIONS UPON THE PERMEABILITY OF PUTNAM CLAY MEMBRANES

is inversely related to the amount of swelling. This is true with all colloids except the Iredell, in which the differences in swelling of the various sols is

very small. Such a relationship should naturally be expected, since swelling results in a decrease in the effective pore volume of the clay. H- clays were found to swell less than Ca- and Ba- clays; and the H- systems were more permeable than those saturated with Ca and Ba ions. Apparently, the formation of granules that do not change their volume when wetted is an important factor in soil permeability. The fact that H- clays swell less and are more permeable than Ca- saturated clays throws considerable doubt upon the direct effect of liming acid soils on soil granulation and permeability.

It is noted that K-saturated clays occupy an intermediate position between the Na- and Li- systems and those saturated with H, Ca, and Ba ions. The higher permeability of the K- clays over the Na- and Li- systems is due to the low swelling of the former. Since the K- colloids are dispersed their relative

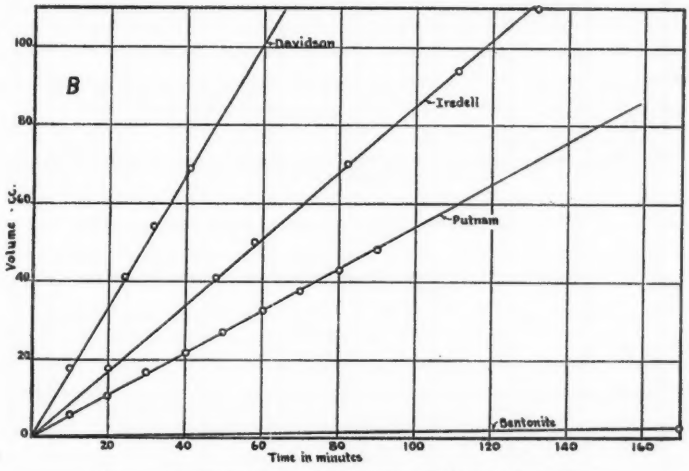


FIG. 6. PERMEABILITY OF DIFFERENT H-CLAY MEMBRANES

permeabilities are not so high as the flocculated H- and Ba- suspensions. The data showing the effect of the exchangeable cations on the permeability of clay membranes indicate that the rate of percolation is dependent upon the degree of dispersion and the extent of swelling of the colloids.

Comparisons of the effect of the chemical nature of the colloidal complex on the permeability of clay membranes are shown in figures 6 to 8 inclusive. These results show that irrespective of the nature of the adsorbed cation the order of permeability for the different colloids is: Davidson > Iredell > Putnam > bentonite. This order is just the reverse of the swelling and of the SiO_2-R_2O_3 ratios of these colloids. These data point out quite distinctly that the nature of the inner layer has a marked effect upon the hydration of the colloidal particle. The effect of the exchangeable cations appears to be only of secondary importance. Studies on the colloidal material extracted from

the non-erosive Davidson and the erosive Iredell soils have shown that the hydration and state of dispersion of the colloids are important factors in

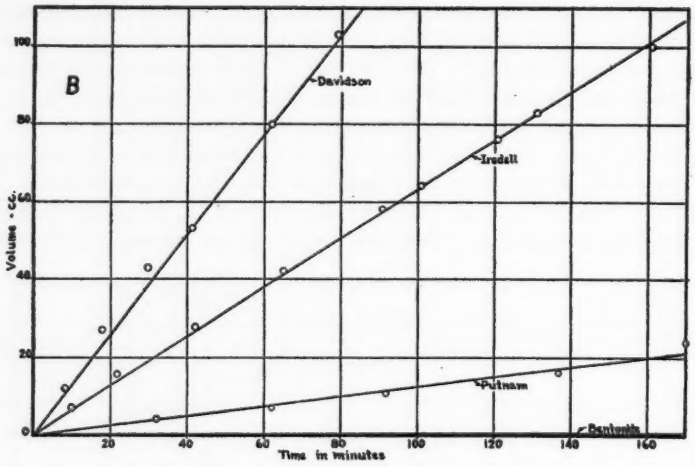


FIG. 7. PERMEABILITY OF DIFFERENT Ca-CLAY MEMBRANES

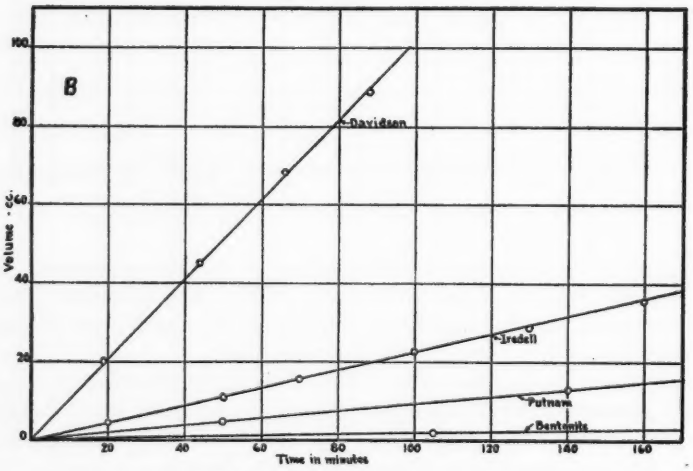


FIG. 8. PERMEABILITY OF DIFFERENT Na-CLAY MEMBRANES

determining the differences in the erosiveness of the two soils. The resistance of the Davidson clay to erosion can be attributed to the non-hydrated and granular condition of the colloidal fraction. Consequently, rapid percolation

of water through the profile is permitted, which in turn reduces the amount of surface run-off and erosion. The relative rates of percolation through the Davidson and Iredell clay membranes are conclusive evidence of the greater permeability of the Davidson soil. The dense, impermeable membranes formed by the Iredell colloid (19) indicate quite clearly that the permeability of the B horizon of this soil is due to the hydrated and deflocculated state of the colloids present. The investigation of the stability, hydration, and permeability of the colloids extracted from these soils has made possible a clearer concept of the effect of the physical properties of soils on erosion.

DISCUSSION

A laboratory study of the physical properties of several soils, found under the same environmental conditions, shows that their difference in erosibility is due primarily to the degree of aggregation of the finer fractions. The Davidson clay, a relatively non-erosive soil, is highly aggregated into large aggregates, whereas the Iredell sandy clay loam, a very erosive soil, contains a lower content of much smaller aggregates. The aggregates of the erosive soil are dense, impermeable, and less stable than the large aggregates of the Davidson. These differences manifest themselves in the physical condition of the soil; the B horizon of the Davidson is friable, granular, porous, and permeable to water, whereas the B layer of the Iredell is distinctly plastic, sticky, and impermeable. Suspension of Davidson colloids flocculated irrespective of the nature of the adsorbed cation, or of the amount of NaOH up to 150 per cent saturation, but only the H-, Ca-, and Ba- Iredell colloids flocculated.

No definite relationship existed between the zeta potential and the SiO_2-R_2O_3 ratio of the colloids. This was unexpected in the light of other work but is possibly explained by the fact that the clay acids with low SiO_2-R_2O_3 ratios were more highly dissociated than those with higher ratios, as shown by pH and symmetry value measurements and by the fact that those colloids with low ratios were less hydrated. The Davidson colloids do not swell, irrespective of the nature of the exchangeable cations present; the Putnam and Iredell, however, become hydrated, the Putnam more than the Iredell. These data on charge and hydration of the various clay sols suggest very strongly that hydration is a more important factor than charge in determining the stability of clay suspensions.

Calculations from viscosity measurements of the hydration of the various sols showed that the Putnam was more highly hydrated than the Iredell. The Davidson sols showed a high content of water associated with the clay, but since the swelling determinations showed that it was non-hydrated, and since these sols were all flocculated, it is reasonable to assume that this was occluded water. Swelling was greatest in the Li- and Na- and lowest in the K- systems. In the other systems the order was Ca > Ba > H. Since the swelling of these latter systems is inversely related to their viscosity and relative flocculation time, it appears that the degree of aggregation has considerable influence on the amount of swelling.

Permeability measurements of the clay membranes show that the highly dispersed and hydrated systems are more impermeable than the flocculated and only slightly hydrated systems. The H- clays of all soils were more permeable than the Ca- clays. This, in addition to the greater swelling of the Ca- systems, makes it very questionable as to whether lime has any direct beneficial effect on the physical condition of acid soils. Any improvement in the physical properties of the soil is probably indirect through an increase in the organic matter content of the soil, resulting in the formation of more stable granules.

These data on the flocculation, hydration, and permeability of the Iredell and Davidson colloids explain partially, at least, the differences in their erosiveness.

SUMMARY

The erosiveness of the Iredell is due to its ease of dispersion and to the dense, impervious nature of the B horizon. Hydration is an important factor in its dispersion.

The non-erosive nature of the Davidson clay is due to the non-hydrated condition and the high degree of flocculation of the colloidal fraction into large porous and stable aggregates.

The Davidson colloids flocculated irrespective of the kind of exchangeable cations on the complex, whereas only the H-, Ca-, and Ba- Iredell systems flocculated.

Electrokinetic potentials of the Iredell, Davidson, and Putnam sols were practically the same, indicating that hydration, rather than charge, was the main contributing factor to stability of the suspensions.

Swelling was in the order Bentonite > Putnam > Iredell > Davidson. . . This is the reverse of the SiO_2–R_2O_3 ratios.

The K, Na, and Li cations showed no definite order of effect on the swelling of the colloids. The Ca, Ba, and H decreased swelling in the order named.

Permeability of the different clay membranes was in the order: H > Ba > Ca > K > Na > Li.

These physicochemical properties of the colloids are paramount factors influencing the erosiveness of soils.

REFERENCES

(1) ANDERSON, M. S. 1929 The influence of substituted cations on the properties of soil colloids. *Jour. Agr. Res.* 38: 565–584.

(2) ANDERSON, M. S., AND MATTSON, S. 1926 Properties of the colloidal soil material. U. S. Dept. Agr. Bul. 1452.

(3) ANTIPOV-KARATAJEV, I. N. 1930 Ueber die Anwendung der Filtrationsanalyse bei der Untersuchung der für die Bodendispersitat massgebenden Faktoren. *Kolloidchem. Beihefte* 31: 374–417.

(4) BARTELL, F. A. 1921 Progress Report on Soil Erosion Experiments. Bureau of Public Roads, U. S. Dept. Agr. in cooperation with N. C. Dept. Agr.

(5) BAVER, L. D. 1929 The effect of the amount and nature of exchangeable cations on the structure of a colloidal clay. Missouri Agr. Exp. Sta. Res. Bul. 129.

(6) BAVER, L. D. 1933 Soil porosity as an index of structure. *Proc. Amer. Soil Survey Assoc. Bul.* 14: 83–85.

(7) BAVER, L. D. 1934 A classification of soil structure and its relation to the main soil groups. *Proc. Amer. Soil Survey Assoc. Bul.* 15: 107–109.

(8) BAVER, L. D., AND RHOADES, H. F. 1932 Aggregate analysis as an aid in the study of soil structure relationships. *Jour. Am. Soc. Agron.* 24, pp. 920–930.

(9) BENNETT, H. H. 1926 Some comparisons of the properties of humid-tropical and humid-temperate American soils, with special reference to the indicated relations between chemical composition and physical properties. *Soil Sci.* 21: 349–375.

(10) BRADFIELD, RICHARD 1923 The nature of the chemical reactions of colloidal clay. *Colloid Symposium Monog.* 1: 369–383.

(11) BRADFIELD, RICHARD 1925 The chemical nature of colloidal clay. *Jour. Amer. Soc. Agron.* 17: 253–270.

(12) BURR, W. W., AND RUSSEL, J. C. 1927 The importance of organic matter in soil structure and tilth. *Abs. Proc. First Internatl. Cong. Soil Sci.* 1: 67.

(13) DICKSON, R. E. 1929 The results and significance of the Spur (Texas) run-off and erosion experiments. *Jour. Amer. Soc. Agron.* 21: 415–423.

(14) JANOTA, R. 1928 Ueber die Draintiefen in verschiedenen Bodentypen. *Proc. First Internatl. Cong. Soil Sci.* 4: 737–745.

(15) JENNY, HANS 1932 Studies on the mechanism of ionic exchange in colloidal aluminum silicates. *Jour. Phys. Chem.* 36: 2217-2258.

(16) JENNY, HANS 1933 Soil fertility losses under Missouri conditions. Missouri Agr. Exp. Sta. Bul. 324.

(17) KRUYT, H. R. (Trans. by H. S. VAN KLOOSTER) 1930 Colloids. John Wiley and Sons, New York.

(18) LOTTERMOSER, A., AND RIEDEL, W. 1930 Ueber die Ladung von Kolloidteilchen und ihre Beeinflussung. *Kolloid Ztschr.* 51: 30–39.

(19) LUTZ, J. F. 1934 The physico-chemical properties of soils affecting soil erosion. Missouri Agr. Exp. Sta. Res. Bul. 212.

(20) MATTSON, SANTE 1926 The relation between the electrokinetic behavior and the base exchange capacity of soil colloids. *Jour. Amer. Soc. Agron.* 18: 258–270.

(21) MATTSON, SANTE 1928 The influence of the exchangeable bases on the colloidal behavior of soil materials. *Proc. First Internatl. Cong. Soil Sci.* 2: 185–198.

(22) MEYER, K. H., AND MARK, H. 1930. Der Aufbau der hochpolymeren organischen Naturstoffe. Akad. Verlagsges, Leipzig.

(23) MIDDLETON, H. E. 1930 Properties of soils which influence soil erosion. U. S. Dept. Agr. Tech. Bul. 178.

(24) MIDDLETON, H. E., ET AL. 1932 Physical and chemical characteristics of the soils from the erosion experiment stations. U. S. Dept. Agr. Tech. Bul. 316.

(25) MILLER, M. F., AND KRUSEKOPF, H. H. 1932 The influence of cropping and methods of culture on surface run-off and soil erosion. Missouri Agr. Exp. Sta. Res. Bul. 177.

(26) SLATER, C. W., AND BYERS, H. G. 1931 A Laboratory Study of the Field Percolation Rates of Soils. U. S. D. A. Tech. Bul. 282.

(27) WIEGNER, G. 1924 Dispersitat und Basenaustausch. *Proc. 4th Internatl. Soc. Soil Sci.* Comn. 2: 390–424.

(28) WINTERKORN, H. F., AND BAVER, L. D. 1934 Sorption of liquids by soil colloids: I. Liquid intake and swelling by soil colloidal materials. *Soil Sci.* 38: 291–298.

THE INFLUENCE OF EXCHANGEABLE SODIUM IN THE SOIL ON ITS PROPERTIES AS A MEDIUM FOR PLANT GROWTH

E. I. RATNER

Scientific Research Institute for Fertilizers, Moscow, U. S. S. R.

Received for publication March 4, 1935

The experimental work reported in this paper deals with the problem of the influence of increasing amounts of exchangeable sodium in the soil on plant growth and on the physical properties of soils.

EXPERIMENTAL

The first experiment on the influence of exchangeable sodium in the soil on plant growth was carried out by the author in 1930, with chernozem soil, into which was introduced 33.4 m.e. of exchangeable sodium per 100 gm. of soil, representing 71 per cent of the total exchangeable bases. This was obtained by treating the soil with a normal solution of NaCl, with subsequent removal of the salt first with water and then by dialysis. After these treatments the soil contained the quantity of exchangeable sodium mentioned and but traces of chloride ion. The water suspension of the soil had a pH of 7.6.

Each of two 250-gm. samples of the artificial solonetz obtained in this way, was carefully mixed with 1,200 gm. of washed quartz sand, fertilized with Hellriegel's mixture, and placed in small containers suitable for the growing of plants. To two other weighed samples, besides Hellriegel's mixture, gypsum was added in an amount proportional to the exchangeable sodium.

Oats were planted in these receptacles. In those containing no gyspum the seeds germinated very slowly and died almost immediately. But in the containers to which gypsum had been added the plants developed normally and gave a normal yield.

It thus appeared that 33.4 m.e. of exchangeable Na, amounting to 71 per cent of the total of exchangeable bases, in this chernozem soil was fatal to the plants, notwithstanding the fact that they were fully provided with nutritive substances in the form of Hellriegel's mixture and in spite of a six-fold dilution of the soil with sand.

The experiment with the chernozem soil was repeated in greater detail. In order to create in the soil various relations between the exchangeable forms of calcium and sodium, the soil was first treated with 0.05 *N* HCl until all the exchangeable bases were removed, and then, after complete removal of HCl, it was treated with a diluted solution of NaOH and $Ca(OH)_2$ in various proportions calculated to satisfy the total exchange capacity of the soil, equal to 52 m.e. per 100 gm. of soil.

After a 10 days' reciprocal action of the soil with the reagents introduced, the excess of fluid was evaporated in the air, and the soil was dried, ground in a mortar, and passed through a 1-mm. sieve.

With the soils obtained in this way pot experiments were carried out in small containers holding 600 gm. of soil each. To each container were added 0.2 gm. N and 0.2 gm. K_2O (mixture of KNO_3 + NH_4NO_3) and 0.1 gm. P_2O_5 (double superphosphate).

In 1933 the experiment was carried out with oats. In 1934 spring wheat was sown on the same containers, and half doses of the fertilizers indicated were again introduced.

In table 1 are shown the yield data for both years and also the pH of the soil (in water) before the start of the experiment. Plate 1 shows the wheat in this experiment.

As seen from table 1 in this experiment also, the substitution of about 70 per cent of the exchange capacity of the soil by sodium proved fatal to the

TABLE 1

The influence of increasing amounts of exchangeable sodium in the soil on the growth of oats and wheat

SOIL CONTENT OF EXCHANGEABLE Ca-Na IN PERCENTAGES OF THE TOTAL EXCHANGE CAPACITY	pH OF WATER SUSPENSION	YIELD OF OATS, AIR-DRY BASIS	YIELD OF WHEAT, AIR-DRY BASIS
		gm.	*gm.*
100 per cent Ca	6.68	14.9	17.6
85 per cent Ca + 15 per cent Na	6.73	14.7	16.9
70 per cent Ca + 30 per cent Na	7.11	15.4	17.0
50 per cent Ca + 50 per cent Na	7.32	13.2	14.5
30 per cent Ca + 70 per cent Na	7.86	Plants died soon after germination	

plants, whereas the replacement by the latter of up to 50 per cent of the total exchangeable bases resulted in only a delay in the germination of the seeds and was reflected to a much smaller degree in the yield.

Further experiments in this direction were made with natural non-carbonate solonetz of the zone of chestnut soils of the European part of the U.S.S.R.

The soils for the experiments were from horizon A (upper elluvial horizon, 15–20 cm. thick) and from horizon B_1 (the illuvial horizon [columnar] lying lower, 15 to 20 cm. thick). Some of the characteristics of these soils are shown in table 2. In all the soils the horizon of effervescence lies lower than B_1.

In order to remove the exchangeable sodium, the soils were treated with gypsum, introduced in somewhat greater amounts than were apparently necessary from the calculation of exchangeable sodium, and further they were washed several times with water, in order to remove the products of reaction. The control soils were washed with water in order to equalize the possible action of the washing itself.

With the soils thus obtained pot experiments were conducted. On the first

soil mentioned in table 2, oats were grown; on the second, spring wheat; and on the third, barley.

In order to satisfy the nutritive requirements of the plants, to each vessel, containing 4–5 kl. of soil, were added: 0.5 gm. N and 0.5 gm. K_2O ($NH_4NO_3 + KNO_3$), and 0.1 gm. P_2O_5 (double superphosphate).

In table 3 the yield data of this experiment are correlated with the content of exchangeable Na in the soil. As seen from table 3, the replacement of sodium by calcium led to no marked increase of yield, either in horizon A, in which the

TABLE 2

Characteristics of the alkali soils taken for experiment

SOIL	TOTAL HUMUS	TOTAL ALKALINITY IN HCO_3	pH IN WATER	Cl^-	$SO_4^=$	TOTAL EXCHANGEABLE BASES	EXCHANGEABLE Na	
							Per 100 gm. of soil	Proportion of total exchange bases
	per cent	*per cent*		*per cent*	*per cent*	*m.e.*	*m.e.*	*per cent*
Deep-columnar solonetz of the Valuisk Experiment Station (Lower Volga):								
Horizon A	2.70	0.053	6.94	0.02	Trace	23.5	4.6	19.7
Horizon B_1	1.43	0.070	7.98	0.07	Trace	30.1	10.1	33.6
Deep-columnar solonetz of the Saratov Experiment Station (Lower Volga):								
Horizon A	.....	0.024	7.10	0.04	Trace	21.2	2.2	10.4
Horizon B_1	.....	0.066	7.63	0.06	Trace	32.6	8.5	26.0
Strongly solonetzic soil from the Chongar Peninsula (South of Ukraine, on the border of Crimea):								
Horizon A	2.34	0.023	6.98	0	Trace	13.9	2.6	18.7
Horizon B_1	2.25	0.064	7.78	Trace	Trace	24.5	11.0	45.0

content of exchangeable Na is small, or in horizon B_1, containing considerable amounts of exchangeable sodium, up to 45 per cent of the exchange capacity.

Thus, the pot experiments indicate that within limits a high content of exchangeable sodium in the soil is not in itself detrimental to the normal development of plants. As has been shown, in the chernozem soil, rich in organic matter (9–10 per cent humus), the limit destructive to the plants occurred when from 50 to 70 per cent of the total exchangeable bases was replaced by sodium. Experiments with artificial substrata—artificial humic acid and permutite—completely saturated with sodium indicate that in the case of a soil poor in organic matter, the limit in the content of exchangeable sodium that can be endured by the plant is still higher.

In these experiments, humic acid and permutite saturated with sodium and equivalent in exchange capacity were introduced into sand cultures in which oats supplied with Hellriegel's nutritive mixture were growing. In the

TABLE 3

Influence of exchangeable Na in the soil on plant growth

SOILS	CONTENT OF EXCHANGEABLE Na IN PERCENTAGE OF THE TOTAL EXCHANGEABLE BASES	DRY MATTER YIELD PER VESSEL	
		Soil washed with water only	Soil treated with gypsum and washed with water
		gm.	*gm.*
Deep-columnar solonetz of the Valuisk Experiment Station:			
Horizon A	19.7	37.8	37.3
Horizon B_1	33.6	18.8	19.5
Deep-columnar solonetz of the Saratov Experiment Station:			
Horizon A	10.4	34.7	34.9
Horizon B_1	26.0	17.8	18.2
Strongly solonetzic soil from Chongar Peninsula:			
Horizon B_1	45.0	25.0	25.3

TABLE 4

The influence of exchangeable sodium in the soil on some of its properties

CONTENT OF EXCHANGEABLE SODIUM	pH	DISPERSION-PARTICLES <0.001 MM.	RATE OF CAPILLARY RISE OF WATER WHEN PACKING THE SOIL INTO GLASS TUBES TO A HEIGHT OF 12 CM.
		per cent	
Check*	6.2	1.4	During 4 hrs. 20 min. the water rose continuously
0.9 m.e., or 1.9 per cent of total exchangeable bases	6.9	1.9	During 9 hrs. 5 min. the water rose continuously
5.1 m.e., or 10.6 per cent of total exchangeable bases	7.2	9.0	During 20 days the water rose 8.5 cm.
20.5 m.e., or 42.7 per cent of total exchangeable bases	7.4	26.4	During 20 days the water rose 2.2 cm.
33.4 m.e., or 70.6 per cent of total exchangeable bases	7.6	29.1	During 20 days the water rose 1.8 cm.

* Original soil, containing no exchangeable sodium, washed with water.

first year, the plants perished after the introduction both of humic acid and of permutite. In the second year the plants perished after the introduction of humic acid, whereas after permitute they developed normally and gave a yield approaching that following the use of permutite plus gypsum.

If we attempt to apply to field conditions the data obtained from pot cultures we must introduce an essential correction, for the physical properties of soil substantially change when even comparatively small amounts of exchangeable sodium are introduced. This may be seen in table 4 and in figure 1, in which is shown the change in dispersion, in rate of capillary rise of water, and in filterability of the chernozem soil artificially enriched by increasing amounts of exchangeable sodium. This was done by treating the soil with a solution of NaCl of various concentrations, with subsequent removal of the salts with water and then by dialysis.

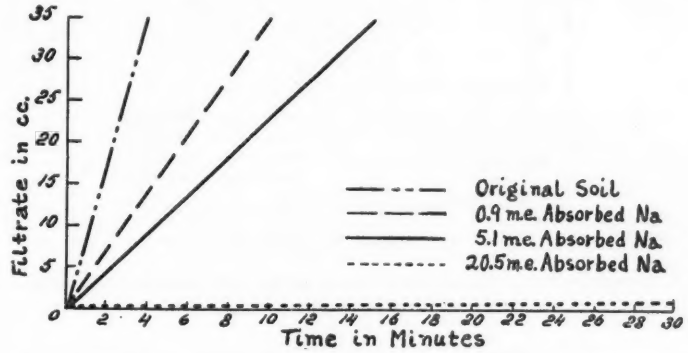


FIG. I. INFLUENCE OF INCREASING AMOUNTS OF EXCHANGEABLE SODIUM UPON THE FILTERABILITY OF CHERNOZEM SOIL

TABLE 5

The effect of 2 and 3 years' application of various types of nitrogen fertilizers on the rate at which the water in the soil rises to a height of 12 cm. by capillary attraction

FERTILIZER	AFTER 2 YEARS' APPLICATION	AFTER 3 YEARS' APPLICATION
1. KP	4 hrs.	8 hrs., 10 min.
2. KP + $NaNO_3$	8 hrs., 40 min.	20 hrs.
3. KP + $(NH_4)_2SO_4$	4 hrs.	5 hrs., 30 min.
4. KP + $CO(NH_2)_2$	3 hrs., 45 min.	7 hrs., 20 min.
5. KP + $CaCN_2$	3 hrs., 50 min.	5 hrs., 50 min.

The replacement by sodium of 10.6 per cent of the total exchangeable bases (5.1 m.e.) produced a desired change in the physical properties of the soil. Even the replacement by sodium of only 1.9 per cent (0.9 m.e.) of the total exchangeable bases influenced these properties.

The deleterious effect of relatively small amounts of exchangeable sodium on the physical properties of chernozem soil was further confirmed by another experiment performed during a study of the effect of various types of nitrogen fertilizers on pot cultures. Nitrogen fertilizers—$NaNO_3$, $(NH_4)_2SO_4$, $CO(NH_2)_2$, and $CaCN_2$—were introduced annually for 3 years into the same

soil sample, which was planted to oats. These fertilizers, in addition to superphosphate and K_2SO_4, were added at the rate of 0.5 gm. of nitrogen for each pot containing 5 kgm. of soil. The soil used was the same chernozem as in the previous experiment. At the end of the second and third years of the experi-

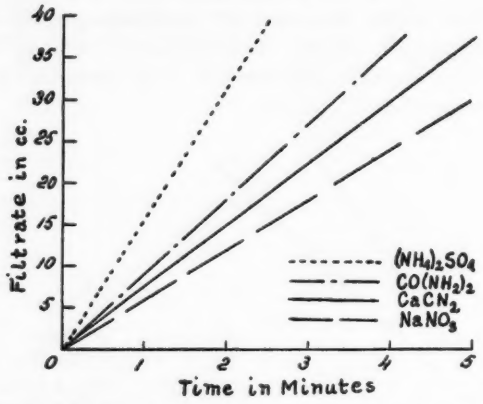


FIG. 2. EFFECT OF THREE YEARS' APPLICATION OF VARIOUS TYPES OF NITROGEN FERTILIZERS ON THE FILTERABIKITY OF THE SOIL

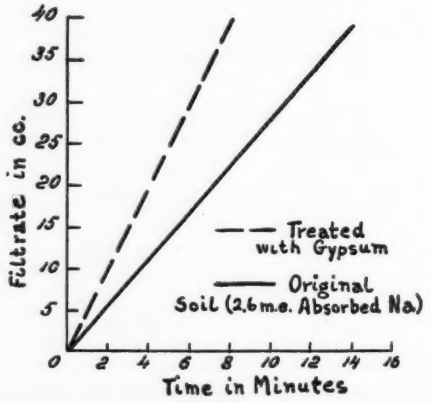


FIG. 3. INFLUENCE OF EXCHANGEABLE Na UPON THE FILTERABILITY OF EXTREMELY SOLONETZIC SOIL, HORIZON A

ment, average samples of soil were taken from the pots, air-dried, ground in a mortar, and passed through a 0.5-mm. sieve. The capillarity and filterability of these samples were then determined.

The results, given in table 5 and figure 2, show that the 3 years' application of $NaNO_3$, which contributed comparatively small amounts of sodium to the

absorptive complex of the soil,[1] produced a considerable retardation in the rate of capillary movement of the water and a decrease in the filterability of the soil. The influence of exchangeable sodium on the physical properties of a natural solonetz soil are shown in table 6 and in figures 3 and 4, which give the corresponding data for horizon A and B of a strongly solonetzic soil from Chongar.

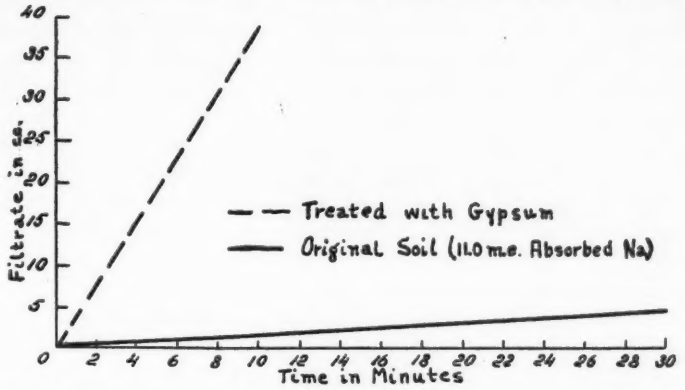


FIG. 4. INFLUENCE OF EXCHANGEABLE Na UPON THE FILTERABILITY OF EXTREMELY SOLONETZIC SOIL, HORIZON B

TABLE 6

Influence of exchangeable Na in strongly solonetzic soil on its physical properties

DESCRIPTION OF SAMPLE	CONTENT OF EXCHANGEABLE Na		CAPILLARY RISE		DISPERSABILITY <0.001 MM. PARTICLES IN PER CENT OF WEIGHT OF SAMPLE		SWELLING VOLUME OF 10 GM. OF SOIL IN WATER	
	M.e. per 100 gm. soil	Per cent of total exchangeable bases	Original soil	Treated with gypsum	Original soil	Treated with gypsum	Original soil	Treated with gypsum
			hours	*hours*			*cc.*	*cc.*
Extremely solonetzic soil from Chongar Peninsula:								
Horizon A (0–15 cm.)	2.6	18.7	7	3	2.7	2.4	10.0	9.8
Horizon B_1 (15–49 cm.)	11.0	45.0	288	36	26.6	4.4	24.0	13.7

These data show that in horizon B, as well as in horizon A, which contains comparatively small amounts of exchangeable sodium, the replacement of

[1] If we assume that all the sodium introduced with the saltpeter was absorbed, then the total amount of sodium taken up by the absorptive complex in 3 years is about 0.05 per cent of the weight of the soil, or about 4.5 per cent of the total exchangeable bases.

sodium by calcium as a result of treatment with gypsum leads to an increase of the filterable capacity of the soil and of the rate of capillary rise of water.

A comparison of the data in table 6 with those in table 4 indicates that the influence of exchangeable sodium on the physical properties of the soil, like that on plants, is greater in the case of a soil rich in organic substances (chernozem) than in the case of a soil poor in the organic substances (soils of the chestnut zone). It may be concluded, therefore, that under field conditions the deleterious effect of exchangeable sodium in the soil on the yield may also be evident in practice with a lower content in the soil than under conditions of pot culture.

These data also show that in the reclaiming of non-carbonate solonetz (in which there is no accumulation of soda) the chief object should be the improvement of the physical properties of the soil, because the content of exchangeable sodium in the soil, up to a certain very high limit, is not in itself a limiting factor in the development of plants. When choosing the dose of the meliorating substance (for instance, gypsum), it is also necessary to proceed from the peculiarities of its influence on the physical properties of the soil. As has been shown elsewhere (5), the physical properties of non-carbonate solonetz are essentially improved with doses of gypsum considerably smaller than would be expected from the computation of the content of exchangeable sodium in the soil.

In conclusion, let us consider the causes of destruction of plants with a very high content of exchangeable Na in the soil.

As has been indicated, soil reaction alone is not a sufficient explanation, for in the case of chernozem containing exchangeable Na to the amount of about 70 per cent of the total exchangeable bases, the reaction in the soil suspensions did not exceed pH 7.6 to 7.8.

Another possible cause of the destruction of plant life might be the accumulation of soda in the soil as the result of hydrolysis of the exchangeable sodium. To determine the possible importance of this factor, in the pot tests described in the foregoing two pots were included containing soil saturated 70 per cent with sodium, 15 per cent with calcium, and with the remaining 15 per cent not saturated with any base.[2] Thus this soil had a kind of "buffer" in the form of an unsaturated 15 per cent of bases which would prevent the accumulation of soda in the soil if any were formed. Both the oats and the wheat in those pots died soon after germination, however, and it is, therefore, difficult to explain the death of the plants by an accumulation of soda in the soil.

It is also very difficult to explain the destruction of the plants by the unfavorable physical properties of the soil, since soil 50 per cent saturated with sodium is very similar in these respects to that 70 per cent saturated; but in the first case the plants developed normally, whereas in the second case they died.

The destruction of the plants might be attributed to the immobilization of

[2] Schematically such a composition of exchangeable bases may occur in the case of solonetz which has been subjected to a process of solodization.

micro-elements in the soil (boron, manganese, etc.) occurring in the same way, as has already been pointed out, as in overlimed soils. But when micro-elements (Sommer-Lippman mixture) were introduced into the soil, the destruction of the plants was not prevented.

Finally, one of the causes of the death of plants when the soil contains a large amount of exchangeable sodium may be the lack of calcium to nourish the plants and, in general, the breaking down of the "calcium régime" in the soil, which, as is well known, acts as a regulator for a whole series of processes connected with plant nutrition.

Experimental verification of the importance of this factor is rather difficult, since introducing a source of calcium (e.g. gypsum) directly into the soil not only supplies the plants with calcium but also changes the character of the soil; on the other hand, supplying the plants with calcium by the method of isolated nutrition is also difficult, since, as is known from Domontowitsch's studies (1), calcium cannot be isolated from the other components of the nutrient mixture without injury to the plant.

Nevertheless, in the light of modern conceptions of the mobility of soil exchangeable bases, depending on the degree to which the absorptive complex is saturated by each of them, this last explanation of the destruction of plant life when there is a relatively high content of exchangeable sodium in the soil seems to be very plausible.

The following circumstances may serve as certain confirmation of the correctness of this explanation: Exchangeable magnesium, up to 50–60 per cent of the total exchangeable bases—as shown by the experiments of Drujinin, (2), O. K., and O. E. Kedrov-Sichman, (3) as well as by our experiments (4)—does not lead to a decrease of yield; whereas an increase of magnesium up to 70–80 per cent of the total exchangeable bases, in the experiments of Drujinin, brought about a sharp reduction of plant growth.

Apparently, in the case of magnesium, as in that of sodium, the cause of the suffering of the plants is the same: the difficulty in the nutrition of the plants with calcium, due to the depression of the hydrolysis of the exchangeable calcium under the influence of the predominance of another exchangeable cation in the soil absorbing complex.

It may be assumed that in the case of cations strongly hydrolyzed and easily dissociated by the soil particles, the depression of the mobility of the exchangeable calcium, in the presence of a predominance of those cations in the soil absorbing complex, is expressed more strongly than in the case of cations weakly hydrolyzed and weakly dissociated. The harmful action of the predomination in the soil of exchangeable sodium must, therefore, be evident earlier than with the predominance of the exchangeable magnesium.

SUMMARY

The influence of exchangeable sodium upon the physical properties of soils (the retardation of the capillary rise of water, the decrease in the filterability,

and the increase of dispersability and swelling) is very clearly defined even when there are only relatively small amounts of exchangeable Na in the soil (several per cent of the total exchangeable bases).

The influence of exchangeable sodium in chernozen soil on plant growth begins to be deleterious under the conditions imposed by pot tests only when it amounts to about 50 per cent of the total exchangeable bases. Death of the plants (oats and wheat) occurs when the exchangeable sodium in the soil increases to 60 to 70 per cent of the total exchangeable bases.

The unfavorable influence of exchangeable Na upon the physical properties of soil, as well as its harmfulness to plant growth, when there is a considerable quantity present in the soil, is more marked in soils rich in organic matter than in poorer soils.

The destruction of plant life in pot experiments when there is a large amount of exchangeable Na is difficult to explain (in the case of non-carbonate soils) by the alkaline reaction of the medium, by the accumulation of soda, or by the unfavorable physical properties of the soil. One of the possible causes of the destruction of plant life may be assumed to be the breaking down in the soil of the calcium régime, and in particular an insufficiency of calcium as one of the elements of plant nutrition.

The question of the limiting amounts of exchangeable sodium remaining harmless for the plant demands further elucidation in relation to carbonate soils. It may be assumed that in carbonate soils this limit is lower than in non-carbonate soils, because of the possibility, in the first case, of the formation of soda in the soil as a result of the exchange reaction between the exchangeable sodium and the carbonates of calcium and magnesium.

The chief object in the amelioration of non-carbonate solonetz should be the improvement of the physical properties of the soil, because its richness in exchangeable sodium, up to a certain very high limit, is not in itself a circumstance disturbing the normal development of plants.

The data presented in this study illustrate the impossibility of obtaining a correct conception of the importance to the plant of the physical properties of soil on the basis of pot experiments.

REFERENCES

(1) Domontowitsch, M. K. 1923 Ueber der Einfluss der Calciums auf die Entwicklung der Wurzeln bei Zea Mais. *Ergebnisse der Vegetations- und Laboratoriumsversuche* (Vorstand, D. N. Prianischnikow) 12: 187–199.

(2) Drujinin, D. W. 1933 Importance of magnesium in fertilizers and in the soil for plant yield. Collection of works *News in soil-fertilizing*, p. 31–55. Moscow [Russian].

(3) Kedrov-Siechman, O. K., and Kedrov-Siechman, O. E. 1934 Influence of the composition of absorbed cations on the development of barley and clover. *Chemisation of Socialistic Agriculture* 12: 9–21 [Russian].

(4) Ratner, E. I. 1933 Lime and gypsum on carbonate-free alkali soils. *Pedologie* 6: 464–475 [Russian].

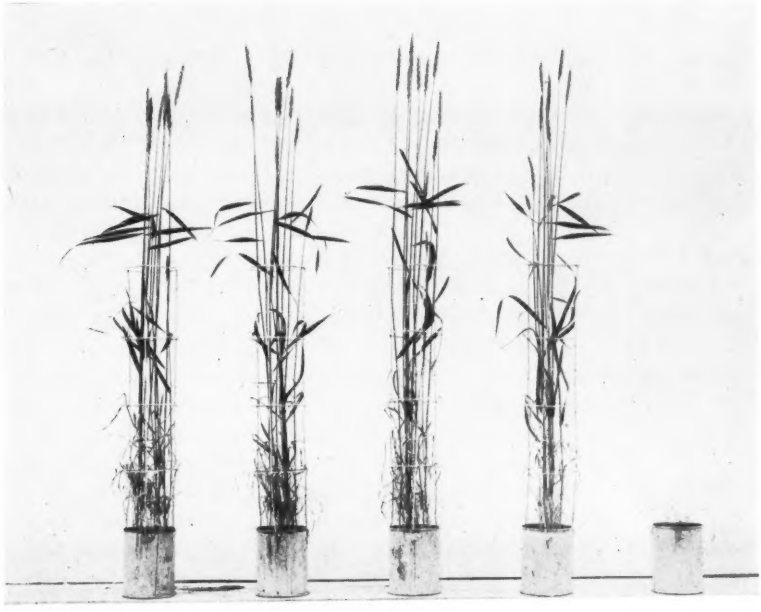
(5) Ratner, E. I. 1935 Use of natural magnesium silicates for the reclaiming of acid soil. *Mineral fertilizers and insecto-fungicides*. No. 2 [Russian].

PLATE

PLATE 1

THE INFLUENCE OF EXCHANGEABLE SODIUM IN CHERNOZEM SOIL UPON THE GROWTH OF SPRING WHEAT

Relation of exchangeable Ca to Na in the soil, left to right: $\frac{100 \text{ per cent Ca}}{0 \text{ per cent Na}}$, $\frac{85 \text{ per cent Ca}}{15 \text{ per cent Na}}$, $\frac{70 \text{ per cent Ca}}{30 \text{ per cent Na}}$, $\frac{50 \text{ per cent Ca}}{50 \text{ per cent Na}}$, $\frac{30 \text{ per cent Ca}}{70 \text{ per cent Na}}$



A SEDIMENTATION TUBE FOR ANALYZING WATER-STABLE SOIL AGGREGATES

RALPH C. COLE AND N. E. EDLEFSEN

University of California

Received for publication February 23, 1935

The tube described in this paper was designed to measure the size distribution of individual and compound particles that are present when a soil is slaked in water. The slaking of soil does not completely break it down to individual particles but permits many fine crumbs or aggregates to remain as such in the water. They are here defined as water-stable aggregates. Information on this state of aggregation is desirable in studying cultural treatments of field soils in relation to their effect on the rate of penetration of irrigation water.

Robinson (6) has suggested that the measurement of structure of soils be carried out as an extension of mechanical analysis. Tiulin (7) considers that the water-stable aggregates are the only true aggregates in the soil and that their measurement gives a clue to the productivity of a soil. Novak (5) prefers mechanical analysis of aggregates to a regular mechanical analysis after complete dispersion as a means of characterizing field soils. Baver and Rhodes (1) suggest aggregate analysis as a means of studying soil-structure relationships. Lutz (4) has offered it as a means of predicting the erosiveness of soils. Bouyoucos (2) has considered the size distribution of particles when a soil is slaked in water as the "ultimate natural structure" of the soil.

The common methods of making mechanical analysis of soils are to separate the coarser particles into various size grades by means of sieves and to separate the finer particles by means of sedimentation or elutriation methods. Bouyoucos (2), however, suggested the use of the hydrometer method for measurements of "ultimate natural structure," but later (3) he concluded that this method is not suitable for measuring particles larger than the upper limit of silt (diameter 0.05 mm).

It is desirable to have a method whereby the whole range of sedimentation velocities can be measured instead of using wet sieving for coarser particles and elutriation or sedimentation for finer particles. The use of wet sieving seems particularly objectionable because the mechanical action necessary in the sieving operation has a dispersing effect on the compound particles, thus giving an abnormally high per cent of fine particles. Evidence of the dispersing action caused by sieving is given in table 1.

The wet sieving was carried on through a series of sieves having the following

openings: 0.991 mm., 0.495 mm., 0.246 mm., 0.104 mm., and 0.053 mm. A 50-gm. sample of soil was placed in the coarsest sieve, which was then put in a shallow pan of distilled water, to a sufficient depth to cover all the soil, and allowed to slake for at least 2 hours. In no soil used by the authors did the state of aggregation of the sample change after slaking for greater lengths of time. Bouyoucos (2) has also found 2 hours to be sufficient for breaking down all the aggregates into their water-stable state, whereas Tiulin (7) found 30 minutes to be sufficient for this slaking for wet-sieving analysis. Novak (5) found 2 hours to be sufficient, except for very ferruginous soils, which required 24 hours to slake down to their water-stable state. After the slaking period, the sieve was raised, drained, and dipped into the pan 50 times, the number of times being arbitrary, except that preliminary tests showed very little additional soil passed through the sieve when a greater number of dippings were made, a fact indicating that most of the smaller material had passed through. The material remaining on the sieve was dried in an oven at 105°C. and weighed. The material passing through was transferred to the next sieve, and the same procedure was followed for the whole series of sieves.

TABLE 1

Analysis of three different samples of Yolo loam by wet sieving and sedimentation methods

Results are expressed as per cent of total sample composed of particles with diameters of less than 0.053 mm.

METHOD	1	2	3
Wet sieving	43.12	40.96	50.37
Sedimentation	18.92	19.60	28.06

The percentage of material (table 1) small enough to pass through the sieve having 0.053-mm. openings is much greater than the percentage of material determined by means of sedimentation and calculation, assuming Stoke's Law, and a particle density of 2.65. This density is admittedly too high for most soil aggregates. If a lower value had been used in this calculation the percentage by sedimentation (table 1) would have been still lower. The differences are so great that they can be explained only on the basis of a mechanical breaking down of the water-stable aggregates in the process of sieving. Evidently the apparatus for analyzing these aggregates must be one that will disturb them as little as possible while determining their size distribution.

The apparatus designed to measure the size distribution of particles when slaked in water, without appreciably breaking up the particles, consists of a brass tube (fig. 1) 30 inches long, inside of which is another brass tube of the same length machined to fit snugly. The inside tube is cut into sections 2 inches long with machined ends, so that there is a close fit at the joints of the various segments. Caps are fitted to screw on both ends of the outside tube so that the segments are held tightly in place. The bottom cap is flat and has

several holes closed with screws, which may be removed for the purpose of drainage. The top cap is hollowed out slightly, and is fitted with a petcock so that the tube can be completely filled with water. There are also a number of holes in this cap closed with screws which may be used for drainage.

The procedure in making a determination is as follows: The bottom cap, with all holes closed, is screwed on the outer tube. The inner tube is put in place and nearly filled with distilled water. Sufficient soil is then added to make 54 gm. of oven-dry soil (2 per cent suspension) and allowed to slake for at least 2 hours. The tube is filled level full of water, the temperature recorded, the top cap screwed on, and the hollow portion of the cap filled with water through the petcock in the top. The tube thus assembled and filled is mounted

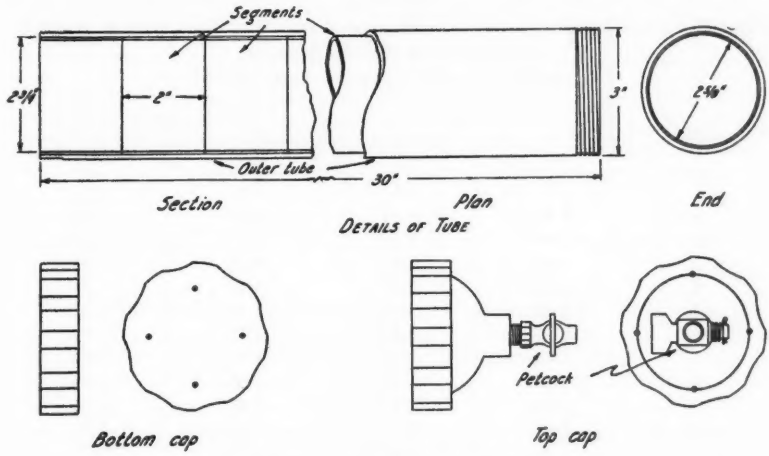


Fig. 1. Diagram of Sedimentation Tube

on a wheel, which is free to turn, and is rotated in a manner which, as explained later, produces a fairly uniform distribution of the particles in suspension.

After mixing is complete, the tube is brought to a vertical position, the settling is allowed to take place parallel to the axis of the tube for a designated time, and then the tube is quickly turned to a horizontal position and allowed to stand 10 to 12 hours so that the particles will settle perpendicular to its axis on the walls of the segments. The water is then drained off by removing the screws from the upper portion of the tube first and allowing the water to run out drop by drop. After draining, which requires from 10 to 12 hours, the tube is dismounted, the inner tube is taken out, the material collected on each segment carefully washed into beakers, the water evaporated, and the residue weighed. Each 2-inch segment is considered as a unit, and the average settling velocity for each is obtained by dividing the time into the distance from the top of the column to the center of each segment.

According to observations on glass tubes, if the tube is completely filled with soil and water, so that there are no air bubbles to stir up the suspension, particles do not materially change their position when the tube is rotated from the vertical to the horizontal.

No air bubbles being present, longer intervals between rotations are necessary at the beginning of the mixing process to get the finer particles distributed throughout the tube. The intervals between rotations are successively shortened until a fairly uniform distribution of all particles is obtained. The plan adopted (method II, table 2) is to turn the tube top down for 1 minute, then invert it for 50 seconds, again for 40 seconds, then 30, then 20, 10, 9, 8,

TABLE 2

Distribution of soil throughout the tube on each segment at zero settling time as obtained by the two methods of mixing explained in the text

(a) and (b) are separate tests under each method

SEGMENT	METHOD I		METHOD II	
	(a)	(b)	(a)	(b)
	gm.	*gm.*	*gm.*	*gm.*
1	8.46	8.11	5.29	3.75
2	3.89	4.76	2.65	3.26
3	3.97	3.83	2.92	3.34
4	3.69	3.60	3.08	3.38
5	3.43	3.27	3.11	3.05
6	3.25	3.20	3.13	3.25
7	2.91	3.20	3.16	3.19
8	2.67	3.06	2.95	4.36
9	2.90	2.81	2.80	3.76
10	2.90	2.65	2.99	3.43
11	3.06	2.85	2.93	3.41
12	2.65	2.88	3.57	3.22
13	2.53	2.48	3.77	3.46
14	2.59	2.15	4.97	3.41
15	2.20	1.98	3.59	3.75

7, 6, 5, 4, 3, 2, and 1 seconds. This method is compared with a method using 30 rotations with uniform intervals between each, as commonly used in mixing for mechanical analysis (method I, table 2). The data indicate that a more uniform distribution of particles is obtained by mixing by method II than by method I.

A number of tests have shown that the aggregates are so stable that the agitation necessary to obtain even distribution, as has been indicated, has a negligible dispersing effect. This seems to be in accord with observations made by Bouyoucos (2).

A number of replications at three different settling periods were made on a sample of Sacramento adobe clay. Some of the data are presented in figure 2.

All of the settling velocities have been corrected to 20°C. using Stoke's formula $v = \frac{Kr^2}{\eta}$, which accounts for replicates not always occurring at the same value for v. The replicates for any settling period give good checks. The data

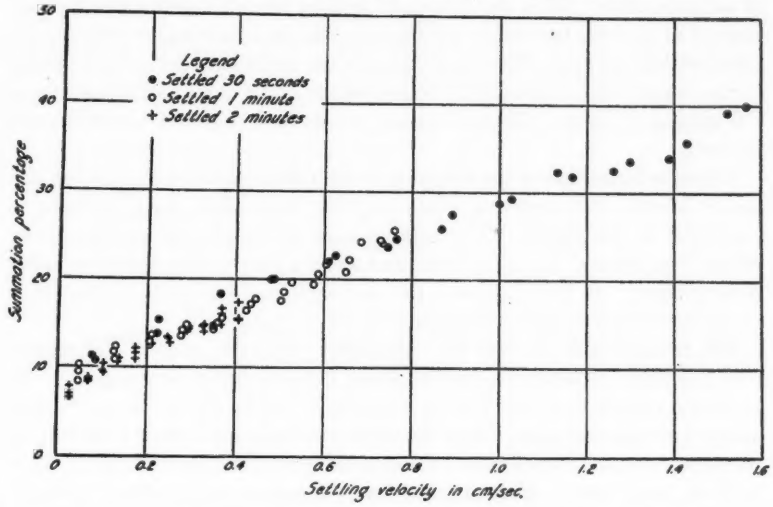


FIG. 2. PERCENTAGE OF PARTICLES HAVING SETTLING VELOCITIES EQUAL TO OR LESS THAN VALUES INDICATED ON THE GRAPH
Settling velocities corrected to temperature of 20°C.

TABLE 3

Percentages of dispersed soil having settling velocities equal to or less than definite values, as measured by the tube and pipette methods

MAXIMUM SETTLING VELOCITIES IN CM. PER SECOND	SACRAMENTO ADOBE CLAY		YOLO LOAM	
	Tube	Pipette	Tube	Pipette
0.25	92.2	93.1	56.8	56.8
0.083	89.3	91.2	49.9	50.2
0.050	88.3	89.7	46.0	45.8
0.025	87.1	86.2	42.0	38.7
0.0125	83.1	83.2	30.2	33.1
0.0083	83.6	80.7	30.0	31.2
0.0042	76.5	72.8	24.1	26.2

further show that the percentage of material having settling velocities equal to or less than any definite amount is practically the same for all settling periods used. The fact that the determinations give good checks for the same maximum settling velocities, whether replicated at the same settling period or determined at a different depth using different settling periods, not only

emphasizes the validity of this method for making accurate measurements of the amount of material in suspension, but supports the soundness of the "mean effective diameter" (mean settling velocity) concept. A mean settling velocity of any group of particles apparently remains constant throughout the course of sedimentation. With the 30-second settling period, it seems that the percentage of particles having low settling velocities is a little higher than for the other settling periods. This indicates that the turbulent effect of the mixing of the sample was not completely dissipated and was greater on the particles of low settling velocities. Shorter settling periods than this should probably not be used.

A further indication of the accuracy of the tube is shown by analyzing dispersed samples of Sacramento adobe clay and Yolo loam, using the tube as compared to the pipette. The samples were dispersed with an electrically driven "egg beater" for 10 minutes and sodium oxalate was added as a dispersing agent. In both instances the pretreatments were alike, so that they should serve as a means of comparing the two methods.

The results (table 3) with the tube agree well with those of the pipette over the range of settling velocities where both methods can be used. The authors do not propose this tube as a substitute for the pipette for mechanical analysis of dispersed soils. With the pipette method, however, it is difficult to measure material in suspension having settling velocities greater than 0.25 to 0.30 cm. per second. With the tube herein described, material in suspension having settling velocities of 1.6 cm. per second can be measured; and by lengthening the tube, greater settling velocities can be studied. Its reasonable accuracy, together with the possibility of its use to investigate the entire range of settling velocities of water-stable aggregates, indicates its usefulness in this field.

In recording the data settling velocities are used here rather than the particle size as calculated by Stoke's Law, because of the presence in such suspensions of both individual and aggregated particles the densities of which may be considerably different. If a crumb and an individual particle were found to have the same settling velocity, the crumb having the lower density would necessarily have the larger mean diameter. For example, let us assume a water stable aggregate to have an apparent density of 1.50. This would mean that the aggregate would have 43.4 per cent pore space, if the density of individual particles is assumed to be 2.65. Let us further assume that in the settling of a water-stable aggregate the water within the pore space is carried down with the particle. The density of the crumb in the form in which it settles would then be 1.50 + 0.434, or 1.934. Applying Stoke's Law and calculating the mean diameter of the crumb, which will have the same settling velocity as an individual particle the density of which is assumed to be 2.65, we find the ratio of the diameters will be 1.33 to 1.00.

A sedimentation tube is described in which settling velocities as great as 1.6

cm. per second can be satisfactorily measured. This is higher than the maximum settling velocities usually measured by sedimentation methods.

Determinations on dispersed samples check well with the pipette over the range of settling velocities covered by both methods.

REFERENCES

(1) BAVER, L. D., AND RHODES, H. F. 1932 Aggregate analysis as an aid in the study of soil structure relationships. *Jour. Amer. Soc. Agron.* 24: 920–930.

(2) BOUYOUCOS, G. J. 1929 The ultimate natural structure of soils. *Soil Sci.* 28: 27–37.

(3) BOUYOUCOS, G. J. 1934 A comparison between the pipette method and the hydrometer method of mechanical analysis of soils. *Soil Sci.* 38: 335–346.

(4) LUTZ, J. FULTON 1934 The physico-chemical properties of soils affecting soil erosion. Missouri Agr. Exp. Sta. Res. Bul. 212.

(5) NOVAK, VACLAR 1932 Contributions to the study of soil structure I. *Bul. Czechoslavak Acad. Agr.* 8: 756–759; [German] 759–761.

(6) ROBINSON, G. W. 1934 The work of Commission I (Soil Physics). *Soil Res.* 4: 125–127.

(7) TIULIN, A. TH. 1928 Same questions on soil structure. II. Aggregate analysis as a help method for determination of the real soil structure. Reprinted from "Results of investigations of the Perm (U. S. S. R.) Agricultural Experiment Station, Division of Agricultural Chemistry," No. 2.

A METHOD FOR MAKING MECHANICAL ANALYSIS OF THE ULTIMATE NATURAL STRUCTURE OF SOILS[1]

GEORGE JOHN BOUYOUCOS

Michigan Agricultural Experiment Station

Received for publication March 25, 1935

In previous works (1, 2, 3), it has been shown that when soils in the dry and field condition are placed in an excess of water, they disintegrate or slake into particles or granules of various sizes. These particles or granules seem to be in an ultimate natural size and stable condition, because according to the hydrometer method (3) they do not get smaller upon standing in water for an indefinite length of time or upon gentle shaking. Indeed, allowing the soils to stay in water for 5 days or shaking them by hand in a liter cylinder from 6 to 30 times resulted in little change in particle size. It would take very long and vigorous shaking or the application of a considerable amount of energy to break up these particles or granules from their natural, stable condition.

A measurement of the ultimate natural structure of soils may have a very significant practical value in such fundamental soil properties as erosiveness, percolation, and tilth.

Since slaking appears to be a fundamental phenomenon and since the slaked product is considered to represent the ultimate natural structure of soils, it has seemed advisable to work out a method for measuring this structural condition. An attempt was previously made to make a mechanical analysis of this structure by the hydrometer method (3). Unfortunately, however, this method cannot measure particles or aggregates larger than about 0.12 mm. in diameter and consequently it does not give a complete analysis and distribution curve of all the particles and aggregates in the soil.

It is the purpose of this paper, therefore, to present the method developed for making a mechanical analysis of the ultimate natural structure of soils, and to give results obtained by the use of the method.

METHOD AND PROCEDURE

The method finally adopted for making a mechanical analysis of the ultimate natural structure of soils is a combination of the sieve method and the hydrometer method. In the sieve method 6 different sieves were employed; namely, 10, 20, 40, 60, 80, and 100 mesh. The procedure consisted of filling a pan 2 inches deep and 8 inches wide with distilled water and placing sieve No. 10 into this pan. Then on this sieve is placed 50 gm. (on oven-dry basis)

[1] Journal Article No. 214 (n.s.) from the Michigan Agricultural Experiment Station.

TABLE 1

Mechanical analysis of the ultimate natural structure of soils and their ultimate mechanical composition

SIEVE NO.	DIAMETER OF SIEVE HOLES	SOIL RETAINED BY SIEVES AFTER SLAKING AND GENTLE STIRRING	SOIL RETAINED BY SIEVES AFTER COMPLETE DISPERSION	CLAY 0.005–.000 MM.	FINE CLAY 0.002–.000 MM.
Davidson clay loam (30 inches)					
	mm.	*per cent*	*per cent*	*per cent*	*per cent*
10	2.00	13.5	0.00	55.2	49.2
20	0.84	31.8	0.04		
40	0.42	32.2	1.00		
60	0.25	8.0	0.30		
80	0.18	4.0	1.16		
100	0.15	2.0	0.86		
Total.....		91.5	3.36		
Irredel loam B					
10	2.00	6.1	0.0	57.0	53.0
20	0.84	21.6	1.4		
40	0.42	40.3	1.2		
60	0.25	7.3	1.1		
80	0.18	5.7	1.3		
100	0.15	4.0	1.3		
Total.....		84.5	6.3		
Susquehanna clay loam (24 inches)					
10	2.00	0.4	0.00	45.4	42.2
20	0.84	3.2	0.26		
40	0.42	21.2	0.06		
60	0.25	15.5	0.08		
80	0.18	22.0	0.44		
100	0.15	6.0	8.20		
Total.....		68.3	9.04		
McKenzie clay A_2					
10	2.00	0.4	0.00	68.4	67.4
20	0.84	6.0	0.10		
40	0.42	15.8	0.20		
60	0.25	8.4	0.44		
80	0.18	4.0	0.60		
100	0.15	4.4	0.40		
Total.....		39.0	1.74		
Ontonagon clay C					
10	2.00	3.8	0.00	84.6	78.6
20	0.84	13.7	0.00		
40	0.42	28.8	0.08		
60	0.25	14.8	0.20		
80	0.18	7.6	0.08		
100	0.15	3.8	0.06		
Total.....		72.5	0.42		

TABLE 1—*Concluded*

SIEVE NO.	DIAMETER OF SIEVE HOLES	SOIL RETAINED BY SIEVES AFTER SLAKING AND GENTLE STIRRING	SOIL RETAINED BY SIEVES AFTER COMPLETE DISPERSION	CLAY 0.005–.000 MM.	FINE CLAY 0.002–.000 MM.
Pease clay 60 inches					
	mm.	*per cent*	*per cent*	*per cent*	*per cent*
10	2.00	0.0	0.00	45.4	43.4
20	0.84	0.2	0.14		
40	0.42	2.0	0.12		
60	0.25	6.2	0.36		
80	0.18	6.6	0.62		
100	0.15	4.8	0.76		
Total.....		19.8	2.00		
Fargo clay loam 0–6 inches					
10	2.00	19.0	0.00	52.0	44.0
20	0.84	10.4	0.66		
40	0.42	24.2	0.84		
60	0.25	16.8	1.10		
80	0.18	7.2	1.50		
100	0.15	3.8	1.00		
Total.....		81.4			
Zanesville silt loam surface					
10	2.00	1.6	0.00	26.0	22.0
20	0.84	7.8	0.42		
40	0.42	17.0	0.44		
60	0.25	15.2	0.36		
80	0.18	8.8	0.02		
100	0.15	7.8	0.16		
Total.....		58.2	0.58		
Fine sandy loam surface					
10	2.00	1.9	1.60	6.6	5.2
20	0.84	1.5	0.80		
40	0.42	1.7	1.10		
60	0.25	9.0	11.00		
80	0.18	23.4	27.00		
100	0.15	22.0	19.60		
Total.....		59.5	61.00		

of lump soil as it comes from the field and after air-drying but not being ground or broken up in any way. The soil is allowed to soak and slake for about 24 hours. Then the sieve is gently shaken in the water, and the soil particles or aggregates smaller than the holes of this sieve go through, and

those larger than the holes of the sieve are retained. Then sieve No. 20 is placed in a second empty pan, the contents of the first pan are gently washed into it, and again the sieve is gently shaken in the water until there is a separation between the material that will go through No. 20 sieve and that which will not go through it. This process is repeated separately and carefully for each sieve. The sieves are then put in the oven, and, after drying, their contents are weighed carefully. In order to prevent loss of material, a sheet of paper is placed under each sieve during drying. All the soil material that went through the finest sieve used, 100 mesh, was saved in a large beaker and was finally mixed with all the material that was retained by the various sieves, and the mixture was dispersed and mechanically analyzed by the hydrometer method. At the conclusion of the final hydrometer reading the soil, now in a completely dispersed state, was again passed through each of the 6 sieves in order to obtain a direct comparison between that amount of the soil material retained by each sieve after slaking only and after complete dispersion, and thus to ascertain the amounts of sand that might have been counted as granules.

The method as described has worked well in obtaining a mechanical composition of the ultimate natural structure of soils. By shaking the sieves in the usual manner under water a satisfactory separation of the particles seems to be attained. At the present time, the sieve method is probably the most practical method for measuring the ultimate natural structure of soils.

The results obtained by the sieve and hydrometer methods are presented in table 1.

An examination of the results in table 1 reveals at once the striking fact that the ultimate natural structure varies considerably with the different soils. It will be noted that the amount of the slaked soil retained by the sieves ranges from 19.8 per cent in the case of Pease clay to 91.5 per cent in the case of Davidson clay loam. In the majority of soils the amount of aggregates retained by the sieves is high, varying from about 60 per cent to 90 per cent. Since the openings of the sieves range from 2.0 to 0.15 mm. in size, it is readily seen that the ultimate natural structure tends to be relatively coarse in the majority of the soils. The results reveal the fact that most of the aggregates in any one soil range in size from about 0.84 to about 0.25 mm.

SUMMARY

When lumps of air-dry soils are placed in an excess of water, they slake or disintegrate into particles or granules of various sizes.

These slaked particles or granules are considered to represent the ultimate natural structure of soils, because they appear to be stable and they require the application of external energy and dispersing agents to break them up further.

An attempt was made to work out a method for making mechanical analysis of this ultimate natural structure of soils. A combination of the sieve method and the hydrometer method was finally adopted for this purpose.

The results obtained show that the ultimate natural structure varies considerably with the different soils but is distinct for each soil. As a general rule the ultimate natural structure of most soils seems to be coarse, ranging in size from about 2.0 to 0.15 mm. Many soils have more than 90 per cent of their particles or aggregates in this range.

REFERENCES

(1) Bouyoucos, G. J. 1924 The influence of water on soil granulation. *Soil Sci.* 18: 103–109.

(2) Bouyoucos, G. J. 1927 Texture and structure of soils as influenced by chemical agents. *Jour. Amer. Soc. Agron.* 19: 788–797.

(3) Bouyoucos, G. J. 1929 The ultimate natural structure of soils. *Soil. Sci.* 28: 27–37.

THE RÔLE OF PLANT CONSTITUENTS IN THE PRESERVATION OF NITROGEN IN THE SOIL[1]

SELMAN A. WAKSMAN AND I. J. HUTCHINGS

New Jersey Agricultural Experiment Station

Received for publication April 12, 1935

Every system which has for its aim the building up of the humus content of the soil, whether preliminary decomposition of the plant and animal residues is carried out in composts or directly in soil, involves a knowledge of the transformation of the three major groups of plant constituents; namely, the carbohydrates, largely the cellulose and hemicelluloses, the lignins and the proteins. Since the process of humus formation consists in the decomposition of some of the constituents of the plant and animal residues and in the preservation and accumulation of others, as a result of the activities of microörganisms, an understanding of the physiology of these organisms is essential. Among the elements most important in plant nutrition that are conserved in the soil by the presence of humus, nitrogen occupies the leading place.

In the absence of humus, nitrogen does not accumulate in the soil and, even when added to the soil, if it is not used rapidly by the growing crop, it tends to disappear by a variety of processes. When fresh plant residues are allowed to decompose, both in soils and in composts, the nitrogen present in these residues, or added to them, or made available through biological activities upon the soil humus is transformed by the agency of microörganisms into complex organic substances; these form one of the most important groups of humus constituents. The plant residues thus play a significant function in the preservation of the nitrogen, both in the compost and in the soil.

Of the various plant constituents, the carbohydrates and the lignins are most important, both in the process of humus formation and of nitrogen conservation. The carbohydrates disappear rapidly in the process of decomposition of the plant residues; the rate of their disappearance depends upon their specific nature, upon the amount of nitrogen available for the growth of the microorganisms capable of attacking them, and upon the conditions favoring the activities of various specific groups of fungi, bacteria, actinomyces, and invertebrate animals. These organisms make use of the energy liberated in the decomposition of the carbohydrates and synthesize considerable cell substance, with the result that mineralized nitrogen is transformed into microbial cell

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, New Brunswick, N. J., department of soil chemistry and bacteriology.

substance. In the case of pure cultures of fungi, it was found (4) that as much as 1 part of nitrogen is consumed for every 30 parts of cellulose decomposed; with mixed cultures of bacteria and fungi this ratio is considerably wider. The function of carbohydrates in the preservation of mineralized nitrogen in soils or in composts thus consists in supplying available energy to the microörganisms, which are able to convert this nitrogen into organic forms.

Lignins, however, play a totally different rôle in the process of nitrogen conservation. They exert a specific effect upon two of the most important forms of nitrogen that find their way into the soil; namely, ammonia and protein: the first is absorbed by the lignin and is held in an absorbed condition until utilized by the plants or microörganisms or oxidized by specific bacteria to nitrate; the proteins combine with lignin, in a physical or chemical manner, giving complexes which are highly resistant to decomposition and which form an essential group of humus constituents (6).

The three most important forms of nitrogen which find their way into the soil; namely, protein, ammonia, and nitrate, are thus affected by the various plant constituents in a variety of processes: 1. Proteins added to the soil, or formed there as a result of microbial action, can either be decomposed, giving rise to ammonia, or, in the presence of sufficient quantities of lignin, are absorbed by the latter to give rise to ligno-protein complexes. The relative concentrations of protein decomposed or absorbed depends on the relative amounts of protein and lignin and upon the conditions of decomposition. 2. Ammonia exists in normal soils in a free state only in very limited concentrations; however, since it is the final product of protein decomposition, it is constantly produced in the soil. It usually does not remain there as such, but is either assimilated in the presence of carbohydrates by the microörganisms and converted into microbial proteins, absorbed by the organic and inorganic soil complexes, or oxidized to nitrates, or assimilated by higher plants, or volatilized and lost to the atmosphere, especially in poorly buffered non-acid soils. 3. The final product of nitrogen transformation in soil, namely, nitrate, can also either be assimilated by microörganisms, in the presence of carbohydrates, or utilized by higher plants, or washed out in the drainage water, or reduced to gaseous forms of nitrogen under anaerobic conditions.

An extensive literature has accumulated on the specific effect of carbohydrate-rich plant residues, especially cereal straw, upon the removal of available nitrogen from the soil by the microörganisms attacking the carbohydrates. In some cases, this effect has even been ascribed (1) to some specific toxic action of the plant materials. It has been shown (2), however, that this effect can usually be overcome by the addition of available nitrogen. No attempt will be made to review this literature. The experiments reported here are limited to a study of the effect of plant material as a whole, in the form of cereal straw, and especially of its carbohydrate (cellulose) and lignin constituents upon the preservation of nitrogen in the soil. Some of the results presented here have already been presented in a preliminary form elsewhere (5).

EXPERIMENTAL

In order to eliminate the interfering action of soil organic matter and at the same time to produce conditions similar to those which prevail in an ordinary soil, sand was selected as the medium for the study of nitrogen transformation by microörganisms. One-kilogram portions of washed sand were placed in a series of small pots. Enough water was added to make conditions favorable for the activities of aerobic microörganisms. All pots received, at the beginning of the experiment, 0.5 gm. KCl, 0.5 gm. $MgSO_4 \cdot 7H_2O$, 0.1 gm. $FeSO_4$, and 2 gm. $CaCO_3$. Two months later, 0.5-gm. portions of K_2HPO_4 were added to each pot; this was repeated again after three months, when 1.0-gm. portions were added.

The pots were divided into several groups. Some received, at definite intervals, varying amounts of cellulose, in the form of ground filter paper; others received lignin (alkali lignin from straw, unless otherwise stated); and still others received ground cereal straw. The nitrogen was used in the form of di-ammonium phosphate or casein; the latter was added as a neutralized alkali solution. All the pots were inoculated with an infusion of fresh soil and incubated at 25–28°C. At definite intervals, the pots were weighed and the moisture content was adjusted, after a thorough mixing of the contents. In the first two analyses, only the ammonia and cellulose contents were determined; after 2, 6, and 11 months' incubation, complete analyses were made of the total residual organic matter, of its different chemical constituents, and of the various forms of nitrogen present. During the first 6-month period, the various pots received 150 gm. of cellulose or straw, 25 gm. of lignin, 18 to 24 gm. of casein, and 4.5 to 7.5 gm. of $(NH_4)_2HPO_4$. At the end of 6 months, 25 gm. of cellulose was added to the corresponding pots and the whole series incubated again for another 5 months. The moisture content was kept at optimum by frequent additions of water when necessary.

The influence of alkali lignin upon the preservation of the two forms of nitrogen is brought out in table 1. When a neutral ammonium salt was added to sand and kept in closed containers and at optimum moisture, whereby losses from drainage and from excessive volatilization were prevented, as much as 27.6 to 44 per cent of the nitrogen was lost. The reaction of the medium was close to neutrality. Active nitrate formation began to take place within two months. Since practically no organic nitrogen was synthesized in these pots, the sum of ammonia and nitrate may be looked upon as representing the total nitrogen present. When lignin was also added, however, its mere contact with the ammonium salt was sufficient to reduce the losses of nitrogen to less than 10 per cent or stop it completely. Some of the nitrogen was at first changed to an organic form, as shown by an increase in organic matter content and in organic nitrogen; later, some of the lignin began to undergo decomposition. No nitrogen was lost, however, in this process. The reaction of the medium in the presence of lignin was changed to slightly acid, although this acidity had no injurious effect upon the process of nitrate formation.

When protein was added to the sand medium, it underwent rapid decomposition and ammonia was set free; largely because of a lack of sufficient buffer-

TABLE 1

Influence of alkali lignin on the preservation of ammonia and protein nitrogen in a sand medium

All data reported per total 1,000 gm. of sand medium

DATE OF ADDITION OR ANALYSIS	$(NH_4)_2HPO_4$	CASEIN	LIGNIN	ORGANIC MATTER LEFT (C x 1.724)	pH	NITROGEN FOUND			NITROGEN LOST, PER CENT OF TOTAL ADDED
						NH_3-N	NO_3-N	Total	
	mgm. N	*mgm. N*	*gm.*	*gm.*		*mgm.*	*mgm.*	*mgm.*	
3/ 7/34	318	.....	..	.....	...	...	...	.....	....
3/26/34	318*	.....	..	.....	...	230	...	230	27.6
4/17/34	318*	.....	..	.....	...	412	...	412	35.2
5/24/34	...	.....	..	0.05	...	531	35	566	40.6
9/18/34	...	.....	..	Trace	6.6	438	102	540	43.6
2/11/35	954†	.....	..	0.58	6.6	372	186	558	41.5
3/ 7/34	318	.....	5	.....	...	...	...	.....	....
3/26/34	318*	.....	5*	.....	...	262	...	262	17.6
4/17/34	...	.....	5*	.....	...	456	...	456	28.3
5/ 4/34	318	.....	10	.....	6.3	...	...	.....	....
5/24/34	...	.....	..	25.29	...	669	73	864	9.4
9/18/34	...	.....	..	28.22	6.4	493	97	902	5.4
2/11/35	954†	.....	25‡	21.86	6.4	473	118	990	0
3/ 7/34	...	408	..	.....	...	...	...	.....	....
3/26/34	...	408*	..	.....	...	94	...	94	77.0
4/17/34	...	816*	..	.....	...	116	...	116	85.8
5/24/34	...	.....	..	0.94	7.4	67	0	154	87.4
6/14–7/27	...	816	..	.....	...	...	...	.....	....
9/18/34	...	.....	..	1.40	7.0	28	87	356	85.5
2/11/35	...	2,448†	..	1.38	6.7	16	118	298	88.0
3/ 7/34	...	408	5	.....	...	...	...	.....	....
3/26/34	...	408*	5*	.....	...	138§	...	.....	66.2§
4/17/34	...	816*	15*	.....	...	232§	...	.....	71.6§
5/24/34	...	.....	..	27.15	7.1	295	46	940	42.4
6/14–7/27	...	816	..	.....	...	...	...	.....	....
9/18/34	...	.....	..	30.91	5.2	193	132	1,130	53.8
2/11/35	...	2,448†	25‡	26.54	5.4	315	288	1,370	44.0

* Added after analysis was made.

† Total nitrogen added per pot.

‡ Total lignin added.

§ No total nitrogen determinations made; the ammonia represents only a part of the nitrogen, since some of the casein was not decomposed and remained as ligno-protein complex; hence, the losses here are no doubt much smaller than could be calculated from the ammonia figures alone.

ing material, much of the ammonia was volatilized, to the extent of 77 to 88 per cent of the total nitrogen added. The reaction of the medium was only

slightly alkaline (pH 7.0–8.4); with the accumulation of nitrates, the reaction became slightly acid. Only a small amount of nitrogen was conserved in the sand medium, for the following reasons: because of the accumulation of free ammonia, nitrate formation by bacteria was considerably delayed; the synthesis of cell substance by the microörganisms decomposing the protein was very small, since the latter was the only source of available energy.

The addition of lignin to the pots receiving casein reduced the loss of the nitrogen. This was brought about, on the one hand, by a delay in the decomposition of the protein, as shown by the large amount of organic nitrogen in the pots containing the lignin; on the other hand, the presence of lignin resulted in binding some of the ammonia, as shown by the fact that considerably larger amounts of this form of nitrogen were found in the pots containing lignin, even after 11 months' incubation. The losses of nitrogen added to the sand medium in the form of casein were reduced, in the presence of lignin, to about one half. Since the ratio of lignin to protein was narrow, about 2 to 1, the conservation of the nitrogen was not complete. It was found in other experi-

TABLE 2

Influence of acid lignin upon the preservation of ammonia and protein nitrogen in a sand medium*

SOURCE OF NITROGEN	AMOUNT OF NITROGEN ADDED	NITROGEN FOUND			NITROGEN LOST, PER CENT OF TOTAL ADDED
		NH_3-N	NO_3-N	Total	
	mgm.	*mgm.*	*mgm.*	*mgm.*	
$(NH_4)_2HPO_4$	1,272	508	103	1,111	13.4
Casein	1,632	62	127	883	45.9

* 20 gm. per pot; period of incubation, 95 days.

ments (6) that when about four parts of lignin are present for each part of protein, the losses of nitrogen can be stopped almost completely.

The specific effect of lignin in preventing the losses of nitrogen from a sand medium was again determined by using acid lignin prepared from rye straw. The results obtained (table 2) fully confirm the previous observations on the effect of alkali lignin. In the case of the ammonia nitrogen, there was again practically no loss, whereas in the case of the protein, the losses were reduced by the presence of the lignin.

The next series deals with the effect of cellulose in preserving nitrogen in a sand medium. The results obtained from this experiment are quite different from those found with the lignin. The nitrogen in the form of the ammonium salt was added in quantities just slightly in excess of the need of the fungi and bacteria decomposing the amount of cellulose added to the pots, as shown by the fact that some nitrogen was always present as ammonia; most of the nitrogen, however, was consumed and transformed into organic compounds by the microörganisms. In the first complete analysis, made on May 24, about 10 gm. of organic matter was found to have been synthesized by the micro-

organisms (14.70 total organic matter − 4.61 gm. cellulose = 10.09 gm. synthesized organic matter[2]). This organic matter contained 757 mgm. of nitrogen (896 mgm. total nitrogen − 139 mgm. ammonia-nitrogen = 757 organic nitrogen), or about 7.6 per cent nitrogen in the humus produced by

TABLE 3

Influence of cellulose upon the preservation of ammonia and protein nitrogen in a sand medium

Per 1,000 gm. of sand medium

DATE OF ADDITION OR ANALYSIS	$(NH_4)_2HPO_4$	CASEIN	CELLULOSE	ORGANIC MATTER LEFT		pH	NITROGEN FOUND			NITROGEN LOST, PER CENT OF TOTAL ADDED
				Total (C x 1.724)	Cellulose		NH_3-N	NO_3-N	Total	
	mgm. N	*mgm. N*	*gm.*	*gm.*	*gm.*		*mgm.*	*mgm.*	*mgm.*	
Control† 2/11/35	954	.....	...	0.58	0	6.6	372	186	558	41.5
3/ 7	318	.....	10	.....	.....	...	...	...	.....	....
3/26	318*	.....	10*	.....	2.58	...	111	...	.....	....‡
4/17	318*	.....	30*	.....	5.97	...	224	...	.....	....‡
5/24	.....	.....	...	14.70	4.61	7.0	139	0	896	6.1
6/14–8/18	636	.....	100	.....	.....	...	...	...	.....	....
9/18	.....	.....	25‖	30.19	15.97	5.4	156	1.2	1,426	10.3
2/11/35	1,590§	.....	175§	18.90	7.15	6.2	137	1.7	1,265	20.4
Control† 2/11/35	.....	2,448	...	1.38	0	6.7	16	118	298	88.0
3/ 7	.....	408	10	.....	.....	...	...	...	.....	....
3/26	.....	408*	10*	.....	6.21	...	94	...	.....	....‡
4/17	.....	816*	30*	.....	5.81	...	85	...	.....	....‡
5/24	.....	.....	...	10.43	1.34	7.5	17	...	928	43.1
6/14–8/18	.....	1,632	100	.....	.....	...	...	...	.....	....
9/18	.....	.....	25‖	12.59	Trace	6.3	18	92	1,422	56.4
2/11/35	.....	3,264§	175§	10.62	0.41	7.1	10	76	1,182	63.8

* Added after analysis was made.

† The data presented here for control pots report only the total amounts of nitrogen added and found; see table 1 for details.

‡ The loss of nitrogen cannot be calculated for these analyses since no total nitrogen determinations were made.

§ Total nitrogen or cellulose added per pot.

‖ Added only on 11/10.

the microörganisms as a result of the decomposition of the cellulose. In the second complete analysis (9/18/34), 14.2 gm. of synthesized organic matter was found per pot; this organic matter contained 1,269 mgm. of nitrogen, or

[2] These figures would have to be modified on the basis of the difference in carbon content of residual cellulose and of humus, since the total was calculated by means of the arbitrary factor, 1.724.

8.8 per cent. The loss of the nitrogen in the pots receiving cellulose was very small, namely, 10.3 per cent, as compared with 43.6 per cent loss of nitrogen in the corresponding pots which did not receive any cellulose. In the third complete analysis (2/11/35), there was found per pot 11.75 gm. of synthesized

TABLE 4

Influence of cellulose and lignin upon the preservation of ammonia and protein nitrogen in a sand medium

Per 1,000 gm. of sand medium

DATE OF ADDITION OR ANALYSIS	$(NH_4)_2HPO_4$	CASEIN	CELLULOSE	LIGNIN	ORGANIC MATTER LEFT		pH	NITROGEN FOUND			NITROGEN LOST, PER CENT OF TOTAL ADDED
					Total (C x 1.724)	Cellulose		NH_3-N	NO_3-N	Total	
	mgm. N	*mgm. N*	*gm.*	*gm.*	*gm.*	*gm.*		*mgm.*	*mgm.*	*mgm.*	
Control* 2/11/35	954	.....	...	..	0.58	0	6.6	372	186	558	41.5
3/ 7	318	.....	10	5	.....	.....	...	...	...	.....	..
3/26	.....	.....	...	..	.....	3.75	...	106	...	.....	..†
3/29	318	.....	10	5	.....	.....	...	...	...	.....	..
4/17	.....	.....	...	..	.....	4.61	...	243	...	.....	..†
4/19–5/ 4	318	.....	30	15	.....	.....	...	...	...	.....	..
5/24	.....	.....	...	..	30.03	7.63	6.2	246	0	1,056	+10.7
6/14–8/18	632	.....	100	..	.....	.....	...	...	...	.....	..
9/18	.....	.....	25§	..	71.72	23.64	5.3	151	3	1,741	+9.5
2/11/35	1,590‡	.....	175‡	25‡	50.86	16.87	5.4	118	2	1,727	+8.6
Control* 2/11/35	.....	2,448	...	..	1.38	0	6.7	16	118	298	88.0
3/ 7	.....	408	10	5	.....	.....	...	...	...	.....	..
3/26	.....	.....	...	..	.....	4.20	...	115	...	.....	..†
3/29	.....	408	10	5	.....	.....	...	...	...	.....	..
4/17	.....	.....	...	..	.....	6.71	...	263	...	.....	..†
4/19–5/ 4	.....	816	30	15	.....	.....	...	...	...	.....	..
5/24	.....	.....	...	..	29.41	0.86	6.4	15	3	1,312	19.6
6/14–8/18	.....	1,632	100	..	.....	.....	...	...	...	.....	..
9/18	.....	.....	25§	..	41.72	Trace	5.9	11	50	1,929	40.9
2/11/35	.....	3,264‡	175‡	25‡	38.29	1.94	6.1	10	18	1,690	48.2

* See table 1.

† No total nitrogen determinations made.

‡ Total added.

§ Added on 11/10.

organic matter, containing 1,126 mgm. of nitrogen, or 9.6 per cent. With the advance of decomposition, the nitrogen content of the residual humus becomes greater, with the result that more and more of the nitrogen is lost. After 2 months, the loss was only 6 per cent of the nitrogen; this increased to 10 per cent after 6 months, and to 20 per cent after 11 months.

When casein was used as a source of nitrogen, similar results were obtained. However, because of the fact that a much larger amount of nitrogen has been added per pot, a greater comparative loss was found to have taken place. After 2.5 months of decomposition (5/24/35), 9.1 gm. of organic matter was synthesized. This organic matter contained 911 mgm. of nitrogen, or 10 per cent on the basis of the humus produced. The same thing is true of the

TABLE 5

Influence of cereal straw upon the preservation of ammonia and protein nitrogen in a sand medium

Per 1,000 gm. of sand medium

DATE OF ADDITION OR ANALYSIS	$(NH_4)_2HPO_4$	CASEIN	STRAW	ORGANIC MATTER LEFT TOTAL (C x 1.724)	pH	NITROGEN FOUND			NITROGEN LOST, PER CENT OF TOTAL ADDED
						NH_3-N	NO_3-N	Total	
	mgm. N	*mgm. N*	*gm.*	*gm.*		*mgm.*	*mgm.*	*mgm.*	
Control* 2/11/35	954	.....	...	0.58	6.6	372	186	558	41.5
3/ 7	318	.....	25	.....	...	...	...	.....	....
3/26	318†	.....	25†	.....	...	30	...	.....	....‡
4/17	318†	.....	50†	.....	...	165	...	.....	....‡
5/24	.....	.....	...	45.99	5.2	60	69	1,703§	+25.6
6/14–7/27	636	.....	50	.....	...	...	...	.....	....
9/18	.....	.....	...	58.27	5.1	19	164	1,842‖	15.2
2/11/35	1,590**	.....	150**	47.55	5.5	9	102	1,475	32.9
Control* 2/11/35	.....	2,448	...	1.38	6.7	16	118	298	88.0
3/ 7	.....	408	25	.....	...	...	...	.....	....
3/26	.....	408†	25†	.....	...	180	...	.....	....‡
4/17	.....	816†	50†	.....	...	21	...	.....	....‡
5/24	.....	.....	...	27.93	7.9	19	23	1,506§	26.0
6/14–7/27	.....	816	50	.....	...	...	...	.....	....
9/18	.....	.....	...	35.34	7.4	12	32	1,750‖	42.7
2/11/35	.....	2,448**	150**	24.22	6.9	9	116	1,542	49.5

* See table 1.

† Added after analysis was made.

‡ No total nitrogen determination made.

§ Accounting also for the 405 mgm. of nitrogen in 100 gm. of straw.

‖ Accounting also for the 607 mgm. of nitrogen in 150 gm. of straw.

** Total added.

second complete analysis, when for 12.6 gm. organic matter synthesized, the organisms transformed 1,312 mgm. of nitrogen into organic forms, equivalent to 10.4 per cent. After 11 months, the amount of organic matter synthesized was 10.2 gm.; this contained 1,096 mgm. nitrogen, or 10.7 per cent. Here, as well, with an increase in the decomposition period, there were a reduction in the amount of humus synthesized and an increased loss of nitrogen. Because

of the excess of nitrogen added in the form of casein, a greater loss of this element took place even in the presence of cellulose. However, the loss was reduced from 88 per cent in the control pots to 64 per cent in the cellulose cultures. Had a greater amount of cellulose or a smaller amount of casein been used, the losses would no doubt have been reduced much further. It is of interest to record here that in all the cellulose pots, nitrate formation was considerably delayed.

The addition of both cellulose and lignin to the pots brought about an added effect upon the preservation of the nitrogen in the sand medium (table 4). In the case of the ammonium salt, all the nitrogen was preserved; there was actually a small gain in the nitrogen content, which may possibly be due to

TABLE 6

Influence of different forms of nitrogen upon the decomposition of straw

SOURCE OF NITROGEN	STRAW USED	NITROGEN ADDED	PERIOD OF DECOMPOSITION	TOTAL ORGANIC MATTER LEFT (C x 1.724)	HEMICELLULOSE LEFT	CELLULOSE LEFT	LIGNIN LEFT
	gm.	*mgm.*	*days*	*gm.*	*gm.*	*gm.*	*gm.*
Control*	50	202†	..	45.00	11.84	15.93	6.00
$(NH_4)_2HPO_4$	50	632	41	.....	.....	11.16‡	.....
Casein	50	816	41	.....	.....	7.40‡	.....
Control*	100	404†	..	90.00	23.68	31.86	12.00
$(NH_4)_2HPO_4$	100	954	78	45.99	8.37	12.82	16.44
Casein	100	1,632	78	27.93	4.78	8.42	12.04
Control*	150	606†	...	135.00	35.52	47.79	18.00
$(NH_4)_2HPO_4$	150	1,590	195	58.27	6.50	8.86	25.18
Casein	150	2,448	195	35.34	1.94	1.08	16.76
$(NH_4)_2HPO_4$	150	1,590	310	47.55	4.42	8.22	17.51
Casein	150	2,448	310	24.22	1.56	1.06	14.04

* Original straw.

† Nitrogen in straw.

‡ Including hemicelluloses.

the activities of nitrogen-fixing bacteria. This gain was evident in all the analyses made. In the pots receiving casein, there was still a considerable loss of nitrogen; however, this loss was reduced after 6 months from 53.8 per cent for the cultures containing lignin alone, and from 56.4 per cent for those containing cellulose alone, to 40.9 per cent when both cellulose and lignin were added. After 11 months, the loss again increased, as a result of the decomposition of some of the synthesized humus. In these pots as well, there was a much greater decomposition of the cellulose, and less humus formed than with ammonium phosphate as a source of nitrogen.

The action of straw in preserving the two forms of nitrogen in the sand medium (table 5) was quite similar to the effect of a mixture of cellulose and lignin. Here as well, the loss of nitrogen added in the form of an ammonium

salt was almost completely stopped; a gain in nitrogen was actually found at the early stage of decomposition of the straw; with the advance in decomposition, however, a loss occurred, which gradually increased. In the case of the casein, the loss of the nitrogen was also reduced to an amount comparable to that lost in the presence of both cellulose and lignin. The presence of nitrogen in the form of protein favored much greater decomposition of the straw, especially the carbohydrates, as a result of which a smaller amount of organic matter accumulation took place.

It is of interest to analyze further the effect of the two forms of nitrogen upon the specific decomposition of the straw as a whole and of its constituent organic compounds in particular. For this purpose, some of the data reported in table 5 are condensed, and additional information is included for comparison (table 6). The results bring out emphatically the fact that casein as a source of nitrogen favors a much more rapid and more complete decomposition of the straw as a whole. The favorable effect of the casein is exerted not only upon the decomposition of the cellulose and hemicelluloses but also upon that of the lignin. This may be due to a number of factors: 1. There is less of the lignin-like complexes synthesized by the bacteria which develop and attack the carbohydrates in the presence of casein than by the fungi in the presence of the ammonium salt; 2. Some of the ligno-proteins formed in the presence of casein may decompose more rapidly than the lignin alone; 3. Protein may be a more favorable source of nitrogen for the lignin-decomposing organisms than is ammonium salt, as found in the case of the cultivated mushroom; 4. The less acid reaction of the sand cultures containing casein (pH 7.9) than of the ammonium phosphate cultures (pH 5.2) favored the development of actinomyces and of other lignin-decomposing organisms; for example, *Coprinus*, a lignin-decomposing organism (3), was found to develop only in the lignin-cellulose-casein cultures.

SUMMARY

A study has been made of the influence of straw and of two of the most important groups of its constituents; namely, cellulose and lignin, in preventing the loss of nitrogen added to a sand medium in the form of an ammonium salt and a protein. The results obtained are sufficient to emphasize the fact that the preservation of the nitrogen in the soil depends on a number of factors, chief among which are the nature of the nitrogen source and the nature of the organic matter added to the soil. The loss of nitrogen from a sand medium was largely prevented, under the particular experimental conditions, by the use of certain forms of organic matter; this resulted in the preservation of the nitrogen in the soil in the form of humus. The rôles of the different plant constituents in the preservation of the nitrogen differ. The function of cellulose and of other carbohydrates consists in supplying energy for the activities of the microorganisms, with the result that the nitrogen is transformed into microbial cell substance; the function of lignin consists in its action as a buffer for the absorption of the ammonia and in the fixation of the protein.

REFERENCES

(1) COLLISON, R. C., AND CONN, H. J. 1925 The effect of straw on plant growth. N. Y. Agr. Exp. Sta. Bul. 114.

(2) SCHEFFER, F., AND KARAPURKAR, Y. M. 1934 Die Abhängigkeit der Nitrifikation von der Zusammensetzung und der Abbauschwindigkeit der organischen Substanz. *Kühn Arch.* 37: 143–172.

(3) WAKSMAN, S. A. 1931 Decomposition of the various chemical constituents, etc. of complex plant materials by pure cultures of fungi and bacteria. *Arch. Mikrobiol.* 2: 136–154.

(4) WAKSMAN, S. A., AND HEUKELEKIAN, H. 1924 Cellulose decomposition by various groups of soil microörganisms. *Actes IV Conf. Internatl. Pedol.* 3: 216–327.

(5) WAKSMAN, S. A., AND HUTCHINGS, I. J. 1935 The function of cellulose and lignin in the preservation of nitrogen in soils and in composts. *Proc. Third Internatl. Soil Sci. Cong.* 1: 163–167.

(6) WAKSMAN, S. A., AND IYER, K. R. N. 1932 Contribution to our knowledge of the chemical nature and origin of humus: I. On the synthesis of the "humus nucleus"; II. The influence of "synthesized" humus compounds and of "natural humus" upon soil processes. *Soil Sci.* 34: 43–79.

AUTHOR INDEX

Allen, M. C. *See* **Vandecaveye, S. C.**

Allison, L. E. Organic soil carbon by reduction of chromic acid, 311–320.

Allison, R. V. Jacob G. Lipman as teacher and director of research, 31–36; *see* **Neller, J. R.**

Andrews, W. B. Effect of nitrogen content of rye on its rate of decomposition, 219–221.

Bartholomew, R. P. Fluorine, its effect on plant growth and its relation to the availability to plants of phosphorus in phosphate rocks, 203–217.

Baver, L. D., and Winterkorn, H. Sorption of liquids by soil colloids: II. Surface behavior in the hydration of clays, 403–419.

Blair, A. W. Jacob G. Lipman and New Jersey agriculture, 25–29.

Bollen, W. B. *See* **Powers, W. L.**

Bouyoucos, G. J. Comparison between the suction method and the centrifuge method for determining the moisture equivalent of soils, 165–171; method for making mechanical analysis of the ultimate natural structure of soil, 481–485.

Brown, P. E. Beginnings and development of soil microbiology in the United States, 49–58.

Carter, L. S. Some chemical and biological changes produced in a Fox sandy loam by certain soil management practices, 223–236.

Cole, R. C., and Edlefsen, N. E. Sedimentation tube for analyzing water-stable soil aggregates, 473–479.

Davis, L. E. Sorption of phosphates by non-calcareous Hawaiian soils, 129–158.

Denison, I. A., and Ewing, S. P. Corrosiveness of certain Ohio soils, 287–299.

Doughty, J. L. Phosphate fixation in soils, particularly as influenced by organic matter, 191–202.

Eaton, F. M., and Sokoloff, V. P. Absorbed sodium in soils as affected by the soil-water ratio, 237–247.

Edlefsen, N. E. *See* **Cole, R. C.**

Ewing, S. P. *See* **Denison, I. A.**

Fudge, J. F. Mathematical relationships between total exchange capacity and absorption of ammonium and potassium by soils, 269–284.

Harris, H. C. Comparison of potassium permanganate and ceric sulfate for the oxidation of cobaltinitrite in the estimation of potassium in KCl solution and in ammonium acetate soil-extracts, 301–309.

Hutchings, I. J. *See* **Waksman, S. A.**

Jenny, H. Clay content of the soil as related to climatic factors, particularly temperature, 111–128.

Joffe, J. S., Kardos, L. T., and Mattson, S. Laws of soil colloidal behavior: XVII. Magnesium silicate—its base-exchange properties, 255–268.

Kardos, L. T. *See* **Joffe, J. S.,** and Mattson, S.

Kelley, W. P. Agronomic importance of calcium, 103–109.

Lamb, John Jr. Availability of soil potassium, 365–381.

Lundegårdh, H. Influence of the soil upon the growth of the plant, 89–101.

Lutz, J. F. Relation of soil erosion to certain inherent soil properties, 439–457.

Mail, G. A. Soil temperature apparatus for field work, 285–286.

Mann, H. B. Relation of soil treatment to the nodulation of peanuts, 423–437.

Mattson, S. *See* **Joffe, J. S.,** Kardos, L. T., and.

Musgrave, G. W. Device for measuring precipitation waters lost from the soil as surface runoff, percolation, evaporation, and transpiration, 391–401.

Neller, J. R., and Allison, R. V. Machine for the subsurface treatment of soils with chloropicrin and with carbon bisulfide for nematode control under field conditions, 173–179.

Powers, W. L., and Bollen, W. B. Chemical and biological nature of certain forest soils, 321–329.

Puri, A. N. New method of estimating exchangeable bases in soils, 159–163; estimation of replaceable Na and K, exchange capacity, and degree of alkalization in alkali soils by ammonium carbonate extraction, 249–253; simple method of estimating exchangeable calcium and other bases in non-calcareous soils, 383–390.

Ratner, E. Influence of exchange sodium in the soil on its properties as a medium for plant growth, 459–471.

Russell, E. J. Jacob G. Lipman and soil science, 3–7.

Schreiner, O. Early fertilizer work in the United States, 39–47.

de'Sigmond, A. A. J. Development of soil science, 77–86.

Snow, L. M. Comparative study of the bacterial flora of wind-blown soil: VI. Death Valley, California, with summary of six soil studies, 181–190.

Sokoloff, V. P. *See* **Eaton, F. M.**

Vandecaveye, S. C., and Allen, M. C. Microbial activities in soil: II. Activity of specific groups of microbes in relation to organic matter transformation in Palouse silt loam, 331–343.

Waksman, S. A. Jacob G. Lipman as an investigator, 11–23.

Waksman, S. A., and Hutchings, I. J. Chemical nature of organic matter in different soil types, 347–363; rôle of plant constituents in the preservation of nitrogen in the soil, 487–497.

Winogradsky, S. Method in soil microbiology as illustrated by studies on Azotobacter and the nitrifying organisms, 59–76.

Winterkorn, H. *See* **Baver, L. D.**

SUBJECT INDEX

Absorption—
  equations—
    Csiky, 279
    Patten and Waggaman, 280
    Wiegner, 282
  of ammonia and potassium by soils and its relation to exchange capacity, 269
Alfalfa, nitrate production from additions of, 229.
Ammonium—
  absorption of, by soils, 269.
  acetate soil extract, composition of, 240.
  complex, hydrolysis of, 277.
  salts, rate of nitrification, 227.
  sulfate, influence on capillary movement of water, 463.
Anions, extraction of, from soils with water, ammonium-acetate, and by displacement, 240.
Azotobacter—
  method in soil microbiology as illustrated by studies on, 59.
  soil conditions affecting activity of, 62.
Bacteria—
  flora in soils of Death Valley, California, 181.
  in wind-blown soil, 181.
  nitrifying, the method in soil microbiology as illustrated by studies on, 59.
  numbers of, in relation to soil treatment, 227.
Base-exchange—*see* also Exchange capacity, Cations.
  capacity—
    estimation by ammonium carbonate extraction, 249.
    relation to calcium, 107.
  complex—
    ammonia substitution in the, and phosphorus absorption, 143.
    potassium substitution in the, and phosphorus absorption, 143.
  properties of magnesium-silicate, 255.
Bases—
  concentration of, in aqueous and absorbed phases, 245.
  exchangeable—
    ammonium carbonate method of determining, 249.
    barium hydroxide method of determining, versus other, 250.
    errors involved in determining, 243.
    extraction with water, ammonium acetate, and by displacement, 240.
    method of estimating, 159, 383.
  presence of, in filtrates after fixation of phosphate by soil, 144.
Bentonite—
  swelling and viscosity of, 448.
  water intake by, 405.
Boron, importance in plant growth, 99.
Calcium—*see* also Lime.
  agronomic importance of, 103–109.
  cyanamid, influence on capillary movement of water, 463.
  exchangeable—
    as affected by cropping, 373.
    method of estimating, in non-calcareous soils, 383–390.
    relationship between, and magnesium-silicate complex, 263.
    relation to exchangeable potassium, 372.
  relation between, in the soil and its concentration in plants, 97.
  relation to—
    alkali soils, 106.
    base-exchange capacity, 107.
    fertilizer, 108
    phosphate availability, 104.
    plant growth, 104.
    soil formation, 105.
    soil structure, 105.
  sulfate, effect on nodulation of peanuts, 425.
Carbon—
  dioxide production—
    and organic carbon and nitrogen balance, 337.
    as affected by plant residues, 235.
    from cellulose, 230.
    relation to nitrification, bacterial numbers, etc., 232.

Carbon—(*continued*)
organic soil, by reduction of chromic acid 311.
Carrol, John Sharkey, an obituary note, 421.
Cations, effect on—
permeability of clay membranes, 451.
viscosity and swelling of clays, 448.
Cellulose—
carbon-dioxide production from, 230.
influence of, on nitrogen preservation in a sand medium, 492.
Ceric sulfate versus potassium permanganate for the oxidation of cobaltinitrite, 301.
Chernozem—
composition of humus in, 358.
filterability of, as influenced by exchangeable sodium, 463.
Chestnut soils, composition of humus in, 359.
Clay—
content of soil as related to climatic conditions, 111–128.
hydration of colloidal, 447.
moisture function, 120.
surface behavior in the hydration of, 403.
Colloidal—
behavior, the laws of soil, 255.
clay membranes, permeability of, 450.
Colloids—
chemical composition of, of Iredell, Davidson, and Putnam, 445.
physico-chemical properties of, 409.
properties of, affecting erosion, 444.
sorption of liquids by soil, 403–419.
swelling of soil, 412, 449.
Copper, importance in plant growth, 99.
Cotton seed meal, nitrate production from, 229.
Cowpeas, phosphorus and fluorine content of, grown in solution cultures, 207.
Dispersion and erosion ratios, 444.
Earthworms in forest soils, 324.
Exchange—
capacity, mathematical relations between total, and absorption of ammonia and potassium by soils, 269–284.
properties, effect on hydration of colloidal clays, 415.
Fertilizer—
effects with and without lime, 233.
work in the United States, 39–47.
Fertilizers, relation of, to calcium, 108.
Fluorine—
bearing phosphates, availability of, 208.
effect of, on plant growth and its relation to availability of phosphorus in rock phosphate, 203–217.
Fungi, numbers of, in relation to soil treatment, 227.
Humus, phosphate fixation by, 195.
Hydrogen—
ion concentration, effect on—
phosphate fixation, 147.
plant growth, 95.
potassium fixation, 148.
peroxide, fixation of phosphorus by peat treated with, 197.
Lignin, influence on nitrogen preservation in sand medium, 490.
Lime, effect on—
crop yield, 234.
nodulation of peanuts, 425.
Lipman, J. G.—
biographical sketch, 1–2.
investigator, 11–23.
New Jersey agriculture and, 25–29.
teacher and director of research, 31–36.
Lysimeters, type of, for study of runoff and percolation, 391.
Magnesium—
relation between calcium and, in the soil and its concentration in plants, 97.
silicate, its base-exchange properties, 255.
Manganese—
importance of, in plant growth, 99.
intake by plants in relation to calcium content of soil, 98.
Marbut, Curtis F., an obituary note, 345.
Microbiology—*see* also Bacteria.
development of soil, in the United States, 49–58.
method in soil, 59–76.
Microörganisms—
activity of, in soil, 331–343.
in forest soil profiles, 323.
specific groups of, effect on organic matter transformation, 338.
straw affecting activity of, 336.
Moisture—
equivalent of soils, determination of, 165–171.
influence on clay content of soils, 120.
loss as surface runoff, percolation, evaporation, and transpiration, 391.

Nematodes, control of, in soils with subsurface treatment, 173.
Nitrate production from various materials, 229.
Nitrification—
rate of, of urea and ammonium salts, 227.
relation to carbon dioxide production, bacterial numbers, and crop yield, 232.
soil processes and their relation to, 228.
Nitrogen—
availability in forest soil layers, 325.
balance, relation to carbon dioxide production, 337.
content of rye and its effect on decomposition, 219.
effect on capillary movement of water in soils, 463.
fixation in Death Valley soils, 188.
lignin effect on preservation of, 490.
preservation in the soil, 487.
Oats, influence of exchangeable sodium on, 460.
Organic matter—
chemical nature of, in different soil types, 347–363.
chromic acid method of determining carbon in, 311.
decomposition in soil, 340.
phosphate fixation as affected by, 191.
proximate composition of, at various periods, 341.
Schollenberger method of determining carbon in, 318.
transformation of, relation to activity of specific microbes, 331.
Peanuts, relation of soil treatment to the nodulation of, 423.
Peat—
heat effects on fixation of phosphorus by, 198.
phosphorus fixation as influenced by, 193.
Phosphate—
availability of, as related to calcium, 104.
fixation of—
by Hawaiian soils, 129.
influenced by hydrogen-ion concentration, 147.
influenced by organic matter, 191–202.
in soils from which replaceable bases have been substituted, 143.
ions, fixation of basic ions accompanying, 144.
rock, *see* Rock phosphate.
Phosphorus—
availability of, from rock phosphate, 203.
fluorine effect on availability of, to plants, 212.
solubility of, in combination with various cations, 199.
Plant—
boron in, growth, 99.
copper in, growth, 99.
growth—
anion effect on cation intake, 94.
as influenced by the soil, 89.
cation effect on anion absorption, 100.
effect of fluorine on, 203.
relation to calcium, 104.
manganese in, growth, 99.
nutrients—
balance in medium, 93.
relation of, in vegetation to nutrients in soil, 97.
roots—
fluorine absorption by, 207.
mechanism of absorption of soil solution by, 94.
Plants—
fluorine and phosphorus content of, 206.
phosphorus availability to, from rock phosphate, 203.
Podzols, chemical composition of humus in, 353.
Potassium—
absorption of, by soils, 269.
availability of soil, 365–381.
cobaltinitrite method for estimating, 301, 366.
exchangeable, as affected by—
cropping, 373.
fertilization, 373.
permanganate versus ceric sulfate for the oxidation of cobaltinitrite, 301.
relation—
between inner concentration of, in leaves of oats and growth, 93.
of exchangeable, to exchangeable calcium, 372.
of total to exchangeable, 372.
to available, in soil and its concentration in plants, 96.
replaceable, estimation of, by ammonium carbonate extraction, 249.
solubility rate of soil, 375.

Rainfall, losses of water from, as surface run-off, percolation, evaporation, and transpiration, 391.
Rock phosphate—
phosphorus availability from, as affected by fluorine, 203.
versus monocalcium phosphate, 211.
Roots, fluorine presence in, 208; *see* also Plant roots.
Rye, effect of nitrogen content of, on its rate of decomposition, 219–221.
Serozem, composition of humus in, 359.
Silica-sesquioxide ratio, effect on hydration of colloidal clays, 415.
Sodium—
absorbed, as affected by the soil-water ratio, 237–247.
exchangeable, effect on—
plant growth, 459–471.
soil properties, 462.
replaceable, estimation of, by ammonium-carbonate extraction, 249.
Soil—
acidity—
estimation of total, 289.
influence of, on corrosiveness of soil types, 293.
relation to calcium, 103.
aggregates, a sedimentation tube for analyzing water-stable, 473–479.
bacterial flora in wind-blown, 181.
clay content of the, as related to temperature, 111–128.
colloidal behavior, laws of, 255–268.
colloids, effect on ion absorption by plants, 94; *see* also Colloids.
conditions affecting activity of Azotobacter, 62.
Davidson series, mechanical and aggregate analysis of, 440.
effect on plant growth, 89–101.
erosion—
effect on clay content of the, 117.
relation to some inherent soil properties, 439–457.
exchangeable sodium in the, its effects on plant growth, 459.
extract—
ammonium-acetate, 303.
composition of 1:5, 238.
formation, relation to calcium, 105.
Iredell series, mechanical and aggregate analysis of, 440.
loss of precipitation waters from the, 391–401.
management practices affecting chemical and biological changes, 223–236.
organic, carbon determination, 311.
peanuts, nodulation as affected by, treatment, 423–437.
potassium, *see* Potassium.
preservation of nitrogen in the, as affected by plant constituents, 487–497.
processes, relation to nitrification, 228.
profile—
corrosiveness of soil types and the degree of development of the, 297.
microörganisms in, 323.
science—
and Jacob G. Lipman, 3–9.
development of, 77–87.
sedimentation tube for analyzing water-stable soil aggregates, 473.
solution—
displaced, salt content of, 238.
mechanism of absorption of, by plant roots, 94.
structure—
and aggregates, 473.
relation to calcium, 105.
ultimate, natural method of determining, 481.
temperature apparatus for field work, 285–286.
types—
organic matter in different, 347.
properties and corrosiveness of, 289.
water ratio, sodium absorption as influenced by, 237.
wind-blown, bacterial flora in, 181–190.
Soils—
absorption of ammonia and potassium by, in relation to exchange capacity, 269.
alkali—
degree of alkalization of, method of estimating, 249.
relation to calcium, 106.
corrosiveness of certain Ohio, 287.
Death Valley, California, character of, 181.
exchangeable bases in, method of determining, 159–163.
forest—
chemical and biological nature of, 321–329.
earthworms in, 324.
nitrogen availability in 325.

Soils—(*continued*)
Hawaiian, sorption of phosphates by, 129–158.
leaching, with acid and its effect on phosphate fixation, 192.
mechanical analysis of the ultimate natural structure of, 481–485.
moisture equivalent, *see* Moisture equivalent.
nematodes in, *see* Nematodes.
nitrification of nitrogenous materials in, 228.
Ohio, corrosiveness of certain, 287.
Oregon (Western), chemical characteristics of, 321.
Pennsylvania, chemical characteristics of, 321.
phosphate fixation in, 129, 191.
subsurface treatment of, for nematode control, 173–179.
Solonetz, characteristics of, 461.
Straw—
decomposition of, as affected by forms of nitrogen, 495.
effect on—
microbial activity, 336.
preservation of nitrogen in sand media, 494.
Sudan grass, growth of in presence of fluorine, 213.
Sulfur, effect on nodulation of peanuts, 425.
Urea—
influence on capillary movement of water, 463.
nitrification of, 227.
Wheat, influence of exchangeable sodium on, 460.

Diagnosis of Fertility Needs

AMONG the foremost needs of the American farmer today is a definite knowledge of the fertility requirements of his own fields. To quickly gain this information, there have been devised several rapid chemical tests of soils and plants. These methods are now gaining in general acceptance.

In the hands of competent agriculturists, these tests are being used to diagnose the plant-food requirements of soils and crops. The American Potash Institute is cooperating in this work to the fullest possible extent. Please write us for particulars and information.

AMERICAN POTASH INSTITUTE, INC.
Investment Building — Washington, D. C.

BRANCH OFFICES: 417 Beans Bldg., San Jose, Calif. · Life Building, Lafayette, Ind. · Mortgage Guarantee Bldg., Atlanta, Ga. · Yates Building, Hamilton, Ont.

You'll Find This Handbook Helpful

MANUAL ON RESEARCH AND REPORTS

Issued by the Committee on Research of THE AMOS TUCK SCHOOL OF ADMINISTRATION AND FINANCE, Dartmouth College

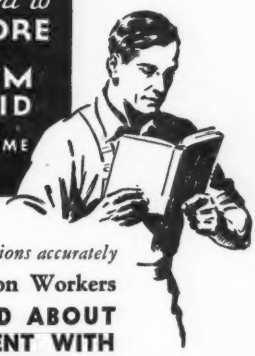
It tells how to go about the investigation of a subject and how to present the material to critical readers. Special application is made to the field of business, economics and public affairs.

"Shop" a Copy by Mail

$1.25

THE WILLIAMS & WILKINS COMPANY — Baltimore, U. S. A.

Farmers want to **KNOW MORE** *about* **CALCIUM CYANAMID** *the* NITROGEN + LIME FERTILIZER



To answer their questions accurately
Experiment Station Workers SHOULD READ ABOUT AND EXPERIMENT WITH 'AERO' CYANAMID
as a source of nitrogen and lime.

A bag of AERO Cyanamid will gladly be supplied, free of charge, to any reader of this Journal who desires to give the material a field trial.

Write **AMERICAN CYANAMID COMPANY**
30 ROCKEFELLER PLAZA, NEW YORK

Manufacturers of
'AERO' CYANAMID — 'AMMO-PHOS'

SOIL SCIENCE

Manuscripts submitted for publication and communications concerning editorial matters should be sent to Dr. Jacob G. Lipman, New Jersey Agricultural Experiment Station, New Brunswick, N. J., U. S. A.

Correspondence concerning business matters should be addressed to The Williams & Wilkins Company, Publishers of Scientific Journals and Books, Mount Royal and Guilford Avenues, Baltimore, U. S. A.

Twenty-five reprints, without covers of articles will be furnished gratis to contributors when ordered in advance. A table giving cost of additional reprints, with an order slip, is sent with proof.

SOIL SCIENCE is issued monthly. Each issue consists of approximately 85 pages at present. Two volumes a year are issued at present. Each volume consists of approximately 500 pages.

Subscription price: $5.00 per volume in the United States and countries within the Postal Union. $5.50 outside the Postal Union.

Claims for copies lost in the mails must be received within 30 days (domestic), and 90 days (foreign), of the date of issue. Changes of address must be received at least two weeks in advance of issue.

New subscriptions and renewals are entered to begin with the first issue of the current volume. Should any issue of the current volume be out of print at the time the subscription order is received, the pro-rata value of such numbers will be credited to the next volume, and the renewal invoice therefore adjusted accordingly.

Subscriptions should be renewed promptly—To avoid a break in your series, subscriptions should be renewed promptly. The publishers cannot guarantee to supply back issues on belated renewals.

Subscriptions, new or renewal, should be sent to the Publishers or to Agents listed below.

Index for Volumes I-XXV is available at $3.00 so long as present supply lasts

AGENTS

For Argentina and Uruguay: Beutelspacher y Cia, Sarmiento 815, Buenos Aires.

For Australia: Angus & Robertson, Limited, 89–95 Castlereagh Street, Sydney.

For Belgium: Henri Lamertin, 58 Rue Coudenberg, Bruxelles.

For the British Empire, except Australia and Canada: Baillière, Tindall & Cox, 8 Henrietta St., Covent Garden, WC. 2, London, England.

For Canada: Wm. Dawson & Sons, Ltd., 91 Queen Street East, Toronto.

For China: Commercial Press, Ltd., Paoshan Road, Shanghai, China.

For Denmark: H. Hagerup's Boghandel, Gothersgade 30, Kjöbenhavn.

For France: Emile Bougault, 48 Rue des Ecoles, Paris.

For Germany: B. Westermann Co., Inc., Zimmerstrasse 35–41, Berlin SW-68, Germany.

For Holland: Scheltema & Holkema, Rokin 74–76, Amsterdam.

For Japan and Korea: Maruzen Company, Ltd. (Maruzen-Kabushiki-Kaisha), 6 Nihonbashi Tori-Nichome, Tokyo; Fukuoka, Osaka, Kyoto, and Sendai, Japan.

For Spain: Ruiz Hermanos, Plaza de Santa Ana, 13, Madrid.

THE WILLIAMS & WILKINS COMPANY

Publishers of Scientific Books and Periodicals

BALTIMORE, U. S. A.

PUBLISHERS OF: *Medicine, Journal of Urology, Journal of Pharmacology and Experimental Therapeutics, American Journal of Tropical Medicine, Journal of Immunology, Journal of Industrial Hygiene, Quarterly Review of Biology, Journal of Bacteriology, Annals of the Pickett-Thomson Research Laboratory, Chemical Reviews, Soil Science, Social Forces, Journal of Comparative Psychology, Mental Measurement Monographs, Occupational Therapy and Rehabilitation, Child Development, The American Journal of Clinical Pathology, Journal of Physical Chemistry, Journal of the Biological Photographic Association, Philosophy of Science, Medico-Legal and Criminological Review.*